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LAND USE PLANNING MODELS:
A LINEAR PROGRAMMING INPUT-OUTPUT APPROACH

by

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A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled *Land Use Planning Models: A Linear Programming Input-Output Approach* submitted by Jerry Ochitwa in partial fulfillment of the requirements for the degree of Master of Arts.

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ABSTRACT

This thesis examines alternate forecasting models used for land use planning and develops a new approach. The *Edmonton Regional Plan* was used as a case study. A review of this plan indicated: (1) the requirements of a land use model in the regional plan; and (2) the weaknesses of present land use forecasting approaches in the region. The major weaknesses of the regional plan's approach was the lack of a reliable forecasting model and the inability to determine the efficient allocation of land. The latter is an important deficiency given that the efficient allocation of land is the primary responsibility of any regional land use plan.

A broad range of land use models were reviewed from the literature. Land use models concentrate more on the allocation of activities (employment, population) to land uses in many zones within the region than the generation (forecasting) of these activities to the region as a whole. Forecasting activities in a large number of small zones a long time in the future is inaccurate. For this reason, it was argued that a macroeconomic model applied in a region was more suitable; concentrating more on forecasting activities for the region as a whole.

Based on the requirements of a regional plan and the inadequacies of alternate land use model approaches a new technique was developed. The new approach is a combination of input-output and linear programming. The input-output model forecasts activities. Then the linear programming formulation developed in the thesis determines the optimal or, that is, efficient allocation of land to uses. The recommendation was that the model presented in general form be implemented for regional land use planning in Alberta.

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CHAPTER I

INTRODUCTION

The decade of the 1970s was one of rapid growth for Alberta. The need to plan and supply infrastructure to areas within the region was a major concern to the regional and municipal governments. As the growth prospects continue, and to meet this need to plan, the Provincial Government, via "The Planning Act, 1977," requires each of the province's eight regions to adopt a regional plan on or before December 31, 1982.[1] For this thesis, the Edmonton Region will be used as a particular example of a region in the province.[2]

The statutory requirements of a regional plan are that it:

(a) Shall provide for the present and future land use and development of the planning region, and

(b) May regulate and control the use and development of land in the planning region.[3]

Also, once the plan is ratified by the minister, a local government can not take any action or make any authorization that is inconsistent with the plan.[4] This includes conformity of statutory plans (which includes general plans), replotting schemes and land use by-laws to regional plans.[5] The plan is, therefore, a policy document which determines the permitted uses of land in a region.

The objective of the "Edmonton Regional Plan, 1979" is:

> The objectives and policies of the Plan are essentially oriented toward optimum land allocation and towards the attaining of desirable and compatible land use relationship with respect to the type, location and density of development. Non-spatial considerations, such as economic and social linkages, behavioural patterns and the timing of development, have been considered but not fully integrated into the policies of the Plan. The Commission will continue its research and analysis into these and other determinants of regional development. As these research efforts materialize, the Plan will be updated and revised.[6]

The Commission, therefore, sees the plan design function as determining optimal land uses in the region. This is consistent with the general view of the planning design function; that is,

> The land use plan design function consists essentially of the allocation of a scarce resource, land, between competing and often conflicting land use activities.[7]

From a planning perspective this:

> ...function is needed to satisfy the aggregate needs for each land use and comply with all the design standards (derived from the objectives).[8]

The above statements on plan design function implicitly assume planning is necessary for optimal land allocation. That is to say, if the "market" had the sole land allocation function, then not all social considerations would be included; and because of market imperfections, land would be allocated inefficiently. This question of the efficiency of the market is not directly approached and discussed in this thesis. This is a theoretical question. The concern here has more of a practical nature. Land use planning is firmly entrenched in Alberta's political-administrative system. Planning determines land uses before the final market allocation. It must perceive the market needs in the future and allocate land based on efficiency today. The concern in this thesis is with this plan design function.

As will be shown below, planners in the Edmonton Region use mostly

staff judgements, rules of thumb and trends. Any efficiency criterion used in the allocation is qualitative and arbitrary. Economists have tools that will determine efficient allocation of resources. The efficiency criterion can be articulated and empirically evaluated. From this, optimal amounts of land uses can be determined. The objective of this thesis is to recommend a land use planning model at the regional and provincial level that will assist a region in making a regional plan. The model, as such, would make forecasts of growth and allocate the growth to land uses based on the efficient use of the resource.

1.1 Study Approach

This thesis does not start, as in typical approaches, with the focus of comparing and analyzing related theories or by extending and testing or applying a particular theory. Rather, it starts with a problem and focuses on recommending the most "useful" land demand forecasting model planners can use at the regional or the Provincial level. The Edmonton Region was used as the case study.

Chapter II discusses the context of this problem; in particular planning in general, and the description and requirements of the Edmonton Regional Plan and the City of Edmonton General Plan. Section 2.1 gives a description and theoretical foundation of land use planning. Further, the importance of a "plan" to this planning process is discussed. The section ends by giving a brief description of the context and purpose of each plan level in the Edmonton region. Section 2.2. and Section 2.3 describe, illustrate and criticize the forecasting techniques used in the Edmonton

Regional Plan and City of Edmonton General Plan, respectively. The purpose of these latter sections is to illustrate the present practices in forecasting, and also identify the needs of a regional plan that a plan design model should satisfy.

Chapter III analyzes a number of land use models that could be used in the regional plan. The models were chosen primarily because they have been applied or have the potential to be applied. This chapter concludes that land use models, per se, are not the "best" modelling approach to assist the planner in their plan design function. Land use models are differentiated from macroeconomic models applied to the region by the former emphasizing growth allocation.

Chapter IV starts out, in Section 4.1, by reviewing the classic macroeconomic models as applied to a region. Without any constraints on research funds, the input-output technique (I-O) was deemed the most suitable. Section 4.2 explains the structure of an I-O table and its use in forecasting. Section 4.3 explains the relationship of linear programming, optimization and efficiency. Section 4.4. briefly discusses interregional I-O models. It was included because of the policy and impact applications in a system of regions. Section 4.5 demonstrates the applications and, thus, usefulness of an I-O model.

Chapter V discusses I-O models and optimization techniques as applied to land use planning. The I-O model can be used in the positive sense by forecasting activities (population, employment) and attaching land use parameters to the activity forecasts. This approach is discussed in Section 5.1. Or, the I-O model's information can be used with a linear programming framework in a normative sense. That is, the optimal amount of each land use can be determined. In Section 5.2 a technique is developed

where this normative planning function can be achieved. In practice, both approaches would be used giving the recommended forecasting approach a quasi two step format. The first step would be to use the I-O in a sensitivity analysis to determine the most probable state of the world. The activities or, that is, the land uses required by the most probable state of the world would serve as an initial condition for the optimization analysis.

Chapter VI concludes with a discussion of the limitations of the model and contributions of the thesis.

Footnotes

[1]Alberta, *The Planning Act,* Statutes of Alberta, 1977, Ch. 89, Pt. 45(1).

[2]The City of Edmonton confirms the necessity to plan for growth.

> "The 1979 Edmonton General Municipal Plan is a statement of the major objectives and policies of City Council which are designed to manage the growth and form of Edmonton as it develops....General Municipal Plan....sets out a development or growth strategy and a clear commitment on the part of the City to programs which will carry out this strategy." [Edmonton Planning Department, *Edmonton General Municipal Plan,* Vol. 1: *Bylaw 6000* (April, 1980); Vol. 2: *Policy Reports,* (April 1980); Vol. 1, Preamble, pp. 1.]

[3]Ibid, *The Planning Act,* Ch. 89, Pt. 46(a)(b).

[4]Ibid, Ch. 89, Pt. 53(1).

[5]Ibid, Ch. 89, Pt. 53(2).

[6]Edmonton Regional Planning Commission, *Edmonton Regional Plan: Draft,* Vol. 1: *Introduction and Characteristics;* Vol. 2: *Policy Reports* (1979); Vol. 1, p. 10. See also Goal 1 referred to in Appendix C, below.

[7]Kenneth J. Schlager, "A Land Use Plan Design Model," *Journal of American Institute of Planners* 31 (May 1965), pp. 103-11.

[8]Ibid.

CHAPTER II

THE PLANNING PROCESS AND CURRENT PLAN REQUIREMENTS

2.1 The Planning Process

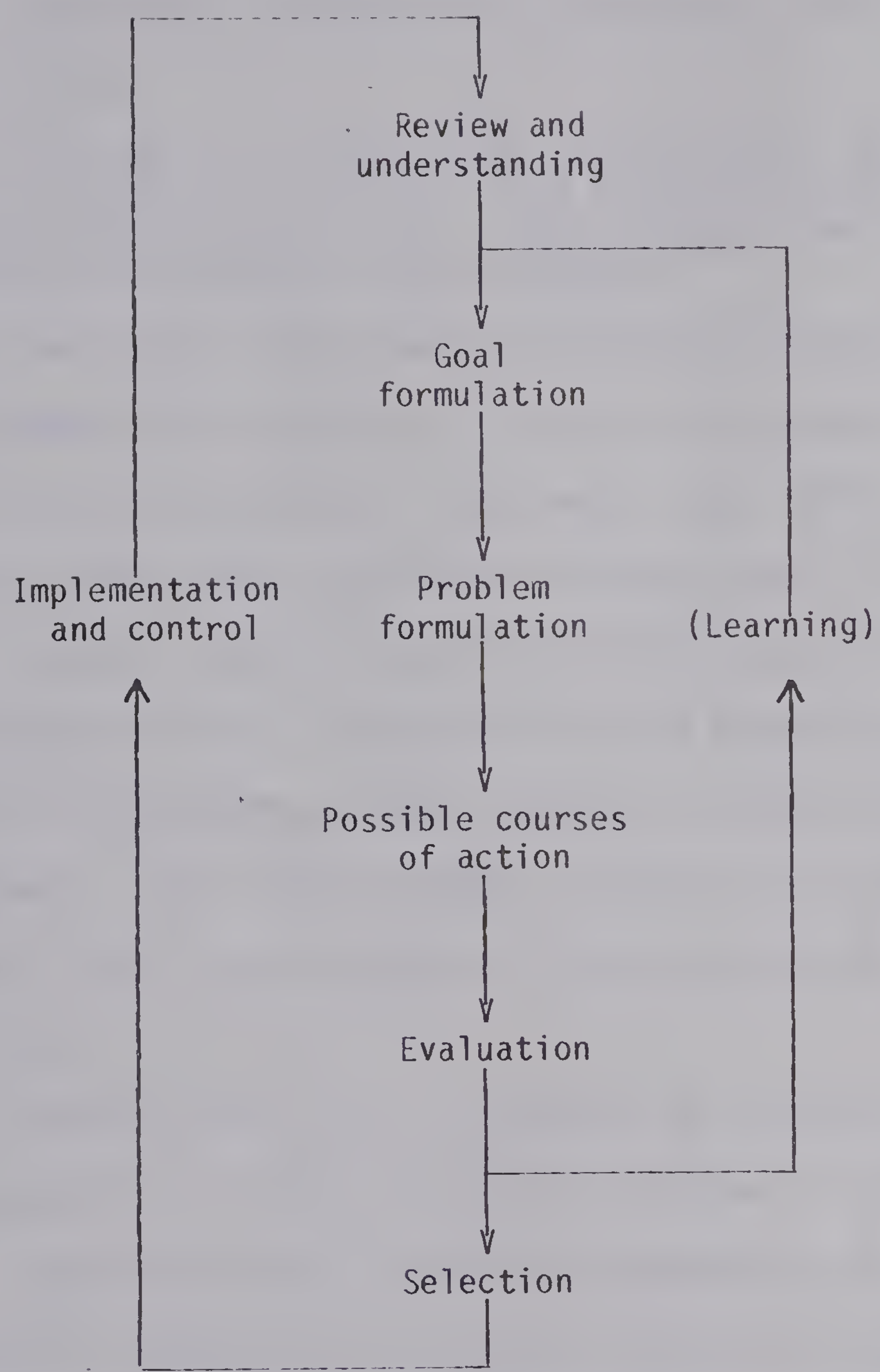
The real world is continually changing. Therefore, planning, in trying to anticipate these changes, must be a dynamic process. Planners must continually review and alter their plans in light of new and unexpected market changes; the process, therefore, is a continual one. As Chadwick aptly describes it:

> Planning is a conceptual general system. By creating a conceptual system independent of, but corresponding to, the real world system, we can seek to understand the phenomena of process and change, then to anticipate them, and finally to evaluate them; to concern ourselves with the optimisation of a real world system by seeking optimisation of the conceptual system.[1]

The stages of this process are illustrated in Figure 1.

This process, however, is not as dynamic as the market. That is, planners can not review and evaluate as fast and as often as the market changes. If this was the case then planning would not have any purpose. The market would be totally responsible for land use allocation. Therefore, at the heart of the planning process is the plan design. The plan outlines land use policy guidelines and becomes a semi-permanent document. After "implementation and control" the plan can be changed as the demands, the market, or politics dictate. There can often be a number of levels or, rather, hierarchy of plans. In the Edmonton Region the

FIGURE 1: The Planning Process



SOURCE: Benjamin Reif, *Models in Urban and Regional Planning,* (London: Leonard Hill Books, 1973) p. 44.

plan is the Regional Plan, then in decreasing order, general plans, district outline plans, neighbourhood outline plans, subdivision plans, and zoning. Each level provides policy guidelines to lower levels. The Regional Plan:

> Shall be used as a framework for municipalities in the preparation of general municipal plans and in the formulation of detailed local land use policies and regulations. The Commission shall indicate the general staging and direction of urban growth...[2]

In the same respect, the general plan outlines policies for development and redevelopment within the city. The policy recommendations are general and apply to lower level plans.[3] Both these higher level plans can be referred to as *structure plans* as distinguished from *lower level plans*. The former contain issues, analysis, and policies concerning all aspects of the development of a local area over the future fifteen years or so; including population, employment, housing, shopping, leisure, transportation and environment. Their scope of their concerns is with all relevant agencies.[4] The lower level plans are more specifically concerned with land development.

A district outline plan is prepared for each new industrial and residential area. These plans are also general in terms of specific land uses. They indicate the general areas appropriate for services, roadways, residential, commercial or industrial land uses. In addition, they may indicate appropriate densities for the plan and staging of growth. The neighbourhood outline plan is a sub-area of a district outline plan. At this level, the actual land use types, services and roadways, are specified. Subdivision is the level where parcels of land are actually created. Finally, after the subdivision is approved, the developer applies for zoning the particular parcels of land.

The regional plans, general plans, district outline plans, and zoning are approved at a political, as opposed to purely administrative, level. The neighbourhood outline plan and subdivision plans are approved by the Municipal Planning Commission (MPC). The MPC is made up of various City Commissioners, City of Edmonton Administration Department heads and citizens. It can be argued that since this group is partially made up of and works closely with the political level, those levels of plans are strongly politically influenced.

The models used for the plan design in the Edmonton Regional Plan and Edmonton General Plan are analyzed below. While the concern is with the Region, it was thought it would be useful to analyze the City of Edmonton's approach also. First, the model proposed in this thesis can be used for a city, metropolitan area, or small region. That is to say, the nature of the problem and the solution proposed by the model is similar for both plans. Second, the city of Edmonton makes up the major part of the Region with respect to its physical size, population, and industry. Third, it shows the interconnectedness or lack of it between the two plan levels. Fourth, it illustrates the current modeling approaches used in the Region to determine its major policy of allocating land to uses. Lower level plans need less forecasting. The planner has more direct control and recent market trends provide efficient forecasts. Thus, the mix of uses within a neighbourhood outline plan or subdivision are determined by rule of thumb based on recent trends and staff opinion: no specific model is used. Their modeling approaches will not be given any further consideration.

2.2 The Edmonton Regional Planning Commission

2.2.1 Model Description

The present Edmonton Regional Planning Commission (ERPC) forecasting technique is described in the *Edmonton Regional Plan.*[5] The forecasts are used for policy and planning guides throughout the life of the plan. In the Plan, they acknowledge that many external and internal forces affect the pattern of land use, but feel it is beyond the scope of the plan to explicitly deal with these influences.[6] As a result, the generative function is a simple extrapolation of previous trends adjusted by staff judgement. The ERPC, in the Plan, also recognizes the existing physical, legal, sociological, cultural, political and psychological constraints on planning and development.[7] Given these constraints and the uncertainty of influencing factors, the modelling approach takes existing land use and, based on *suitability,* recommends the allocation of land to general land use classifications; refer to Appendix A for suitability characteristics. This allocation procedure develops a regional map for each suitability classification. The maps are then overlayed to determine conflicting uses. Conflicts are resolved according to predetermined priorized factors.[8] This modelling approach essentially builds a land use classification map and, therefore, can be classified as a land use approach.

The approach is a *market analysis* approach used as input to a plan design.[9] The forecasting can be described as *estimation.* The model can be described as *general* and *macro;* general for including all land use categories and macro because of the high level of employment and population aggregation. The procedure is intended to recommend the *optimal* land use in the Region though no mathematical optimization technique is used. The

The treatment of time is *dynamic*. The sub-models more *loosely-coupled*, and neither assumptions of *equilibrium* or *dis-equilibrium* processes are present in the model. The equations are *linear*. The system is solved *sequentially* and the solution is a *simulation*.

2.2.2 The ERPC Model

The model's output gives a classification map of the following land-uses:

(a) General Urban

(b) General Urban Reserve

(c) General Industrial

(d) General Industrial Reserve

(e) Agricultural: Farmland Conservation

(f) Agricultural: Country Residential

(g) Resort

(h) Nature Conservation, Open Space and Recreation

(i) Special Control Areas[10]

In the map, the urban and industrial classes designate the respective uses for a minimum of five years and a maximum of 10 years; the urban reserve and industrial reserve for a period of 10-15 years. The output in the form of a land use classification map is derived by the following steps.[11]

Step 1. All existing urban and lands zoned to urban use in existing statutory plans are mapped and take precedent over conflicting uses. Land use projections are then added to these requirements. The land use projections are made in two steps. First, population growth is projected. The Regional population projections are made by assuming a constant

fertility rate and net migration rate (in-migration minus out-migration) and extrapolating the trend to the year 2001. The Region's urban municipal population projections to 1986 are based on ad hoc staff judgements according to:

> The role of the municipality within the regional setting; the recent growth history of the municipality, including 1978 population counts or estimates; previously existing municipal population projections; municipal expressions of growth policies or preferred growth options such as may be found in general municipal plans; existing commitments for future growth; the availability of land for residential development; the potential for, or constraints related to servicing land for development; and the likely location of major industrial, or employment-generating activities in the Region.[12]

Then urban municipal projections to 2001 are made from extrapolations of pre 1986 growth rates. The Regional and municipal projections are compared for consistency. In addition, the percentage of the Regional growth not absorbed in the projected urban municipal growth is used as a figure for the growth of rural municipality and country residential projections.

Second, the land requirements are estimated from the urban municipal population projections. The population absorbing capacity (vacant land times 14 persons/gross acre) is calculated for each urban municipality. Land allocated to urban residential areas is expanded in municipalities that could not absorb all the growth projected in 1986. The residential land requirements to the year 2001 were calculated by using the estimated population growth rates for the years after which their existing vacant land had been filled. The density of 14 persons/gross acre was then applied to get the residential land requirments to the year 2001. Each urban municipality's requirements to 1986 was allocated to the General

Urban land class, and the requirements to 2001 to the General Urban Reserve class.

Step 2. All existing industrial, zoned industrial, and Provincial and municipal land banks are mapped. Industrial land requirements for urban municipalities are projected. "The projections...are based on many subjective judgments...As a general rule, however, it has been necessary to allocate industrial land by using existing commitments and existing projections, and a conceptual approach.[13]

The conceptual approach involves, first, calculating for each industrial sub-class (wholesale storage, grain elevators, light industry, heavy industry) the number of acres per 100 population of communities with different functional roles (resource-oriented, industrial manufacturing, multi-purpose, agricultural service, institutional, holiday-recreation, dormitory). The result is a matrix of land-use sub-classes by different functional roles.[14] Second, each municipality is associated with a functional category and, then, an acreage per 100 population from the matrix. Third, the projected population increase is applied to these ratios to get the land requirements. Rural municipality industrial projections were made on the basis of past commitments and suitability. Industrial and Industrial Reserve are allocated in the same manner as the urban classes.

Step 3. All existing Resort (existing summer villages and resort subdivisions) lands are mapped and take precedent over other uses.

Step 4. All Nature Conservation, Open Space and Recreation Class areas are mapped. This class includes all Primary Wildlife Protection areas, designated stream shorelands, and areas zoned recreation in county plans.

Step 5. Prime farmland is mapped Farmland Conservation.

Step 6. Existing multi-parcel subdivisions and approved multi-parcel subdivisions are mapped Country Residential.

Step 7. Additional land required for Urban Reserve and Industrial Reserve was mapped. In some areas Farmland Conservation was redesignated to these classes.

Step 8. Additional Country Residential areas are mapped in areas of existing concentration and by the indication of special studies. This residential land was allocated on lands of lower agricultural capability.

Step 9. Additional land for potential Country Residential designation is mapped. The procedure takes the rural municipality population projections and applies this to the anticipated density (people per acre) to get the required acres.

Step 10. Natural boundaries and topographical factors are considered and adjustments made to affected classes.

Step 11. All non-prime farmland is mapped Farmland Conversion.

Step 12. Boundaries of valuable sand, gravel and coal areas, Restricted Development Areas, Regulated and Priority Lake Shorelands, Forest Protection Areas and Airport Noise and Safety Control Areas were mapped over existing land classes.

2.2.3 Summary

The above discussion illustrates the complexities of determining policies for land use in a Region. Irregular topography, overlapping growth of uses, numerous existing policies, and the relative importance of different land uses are dealt with by staff judgement. The requirements for both residential and industrial forecasts are medium and long-term.

The residential land requirements are derived from municipal population projections. Up to 1986, the projections are determined by staff judgements in an ad hoc manner. From 1986 on, they were simple trends from the previous projections. The industrial projections combine staff judgement and a conceptual approach. The conceptual approach assumes industrial growth is solely related to population growth. The approaches are very simplistic and one questions the validity and reliability of the results. The method basically assumes all economic growth is a function of population growth. The output is too general to be of much use to lower level plans. The regional plan is more concerned with urban and industrial than other categories. The model's output gives only two sub-classes of each. In addition, there is no mechanism to determine consistency between relative amounts of residential and industrial land uses. On the other hand, these broad categories give enough flexibility to allow autonomy in lower level plans. Also, the model's structure is transparent and, thus, easily understood by policy-makers.

Political input can only be applied in terms of negative policies, restricting growth in certain areas. The model itself does not offer any application to policy or impact analysis. Thus, sensitivity analysis of different growth alternatives were not performed. Also, the effects on different social and occupational groups was not analyzed. The procedure for allocating land involved staff judgements using a set of factors; see footnote 8. In a conflicting use situation, the actual value of one use over another cannot be determined. Also, long run land allocations may be misallocations if the relative value of the land uses change. The Plan used a multiplicity of goals (refer to Appendix C) where it was impossible to determine whether, or to what extent, each was fulfilled.

In short, the ERPC economized on existing data to determine very general projections. The procedure does not have a mechanism to determine if the most efficient allocation has been achieved. The City of Edmonton projections to be discussed below, followed a similar format.

2.3 The City Description and Model

The City's procedure can be described, in general terms, by the following quotation from the *Edmonton General Municipal Plan* and *Edmonton General Plan Workshop Papers*. [15,16]

> With respect to the forecast methodology, it should be noted that all future projections are based upon assumptions of continuation of present growth trends, present land use policies, and present market conditions...The growth forecasts are therefore relatively simple; no precise models were utilized.[17,18]

Residential (single-family, rowhousing, apartments), industrial, commercial retail and service trade, and commercial office land use projections were made separately. Each land use forecast was done differently and no attempt was made to account for consistency between land use types.

2.3.1 Residential

The purpose of the *estimates* are for planning, however, the model itself is a *market analysis*. The residential model can be classified as *partial* as opposed to a *general* model considering all land uses at once. While the City does forecast all types (commercial, industrial, residential), each are done independently and, thus, each forecast is a *partial* analysis of the land market. The model can be also described as *dynamic, macro, loosely-coupled,* and lacks any *equilibriating* or

dis-equilibriating representation. The system is solved *sequentially*. The solution procedure is *simulative* and the relationship between variables *linear*.

The generative function extrapolates previous trends. Population projections are based on constant fertility and migration rates. Household size is based on recent and expected changes. These parameters are determined by staff judgement. Taking the Edmonton Sub-Region's population projections and dividing by the Sub-Region's projected household size gives the projected number of households for the Sub-Region. Based on recent trends and established by staff judgement, these projected households were then allocated to housing types: single-family, row, apartment. The allocation function was done in two steps. Step 1 allocates a percentage of household types to the City based on historical trends. Step 2 allocates household types to areas within the City on an equal basis until the supply ran out and thereafter to areas which had available supply. The output was in terms dwelling units. Projections were made to 1991.

2.3.2 Industrial

The model is a *market analysis* type and the land requirements were *estimated*.

The model can be classified as *partial, dynamic, macro, loosely-coupled* and lacking *equilibrium* or *dis-equilibrium* notions. The system is solved *sequentially*. The procedure is *simulation*. The relationship between variables is *linear*.

The generative function is a straight extrapolation of historical industrial land demand. Also, the allocative function is based on each

area's trend in industrial land demand. The output was in terms of acres. Projections were made to 1991.[19]

2.3.3 Commercial

Separate forecasts were done for office space and for retail and service space.[20] Both, however, were done in exactly the same manner. It is a market analysis model and the space (in square footage) requirements were *estimated*. Since most of the new development would occur in presently developed land, the Planning Department felt it was not necessary to transform the space requirements to acres. It can be classified as *partial, dynamic, macro, loosely-coupled* and lacking *equilibrium* or *dis-equilibrium* notions. The system is solved *sequentially* and the procedure is *simulation*. The relationship between variables is *linear*.

The generative function combines two methods. First, building area per capita for the Sub-Region is calculated. The analysts assumed a moderate increase in the ratio. The ratio is applied to the population projections for the Sub-Region. Second, the ratio of building area per employee is calculated from historic rates. They also assume a moderate increase in the ratio. This ratio is applied to forecasts of employment in those industries using retail-service and office building space. The employment projections are a resolution of two methods. The first can be called a "minimum requirements" method. It assumes a minimum level of employment in each sector for a given level of population. The minimum level of sectoral employment is calculated by tabulation of a cross-section of cities with varied population sizes. The excess above the minimum level is allocated to sectors based on future projections and existing employment concentrations. The relevant sectoral employment-population ratios are

then applied to the Sub-Regions future population to get employment projections. The second method uses a multiple regression technique. Annual employment by sector is regressed on a number of independent variables.[21] Future estimates of the independent variables are made and the sectoral employment forecasts thereafter. Where discrepancies exist between the two techniques, the resolution is made on the basis of staff judgments on the specific industries. The employment forecasts are then multiplied by building area per employee to get building area forecasts. The final space projections was a combination of the above population and employment based techniques.[22] The projections were made to 1991.

The allocation procedure is a staff judgement assumption that 15 per cent of retail-service growth and 65 per cent of the office growth will go to Edmonton's Central Business District. The remaining will go to Edmonton's Outline Area and other areas in the Sub-Region.

2.3.4 Growth Policy Options

Given these forecasts, the City examined three alternate growth allocation forms that could be encouraged by city policy.[23] The *trend* growth option is a continuation of previous trends as forecasted above. The *compact* growth policy option assumes: decentralization of industrial and commercial land uses (primarily office land uses); increased redevelopment in the centre core; and increased density in the suburbs. The *concentrated* option assumes even a greater degree of office decentralization, inner city redevelopment and suburban density increases. This sensitivity analysis was qualitative, performed by staff judgement altering parameters such as densities. No additional or different forecasts were generated. With each option the intended objectives and

land use implications were described. The alternatives were compared in a descriptive format and a combined compact-concentrated option was chosen. Thus, the policies in the general plan reflect this growth allocation scenario.

2.3.5 Summary

The Citys' procedures have a number of drawbacks. For residential and industrial land both the generative and allocative functions are based on previous trends. As such, their validity and reliability are questionable. Political input is limited to negative policies only. Within the model, there are no applications for policy or impact analysis. While the output is disaggregated, the allocation is too general to be used by lower level plans. On the other hand, the procedure has some positive aspects.

The procedure was inexpensive as it relies on existing studies and data. The procedure is easily illustrated and understood.

The commercial forecasts are a little more complex. The generative function is based on two approaches; a population based and an employment based approach. The population based one is a trend extrapolation of building area per capita. The employment based projections combines a minimum requirements and a multiple regression approach. The minimum requirements approach is essentially population driven. The multiple regression approach is not specified in the report. The two approaches are combined by staff judgement and then applied to building area per employee. The allocation was done on an ad hoc basis. The commercial projections appear relatively more valid and reliable, however, it is not quite clear how they were done. As with the above, the political input is

limited and there are no policy or impact applications. Finally, the output is not very comprehensive and, thus, too general for lower level plans.

In summary, the approach uses existing information and relies on ad hoc staff judgement. There is no consistency between alternate land uses. Land value in alternate uses is not determined. Therefore, the planners can not ensure that the most efficient allocation of land has been achieved.

Footnotes

[1]G.A. Chadwick, *A Systems View of Planning* (Oxford: Pergamon Press, 1971), p. 63.

[2]Edmonton Regional Planning Commission, *Edmonton Regional Plan: Draft,* 2 Vols., Vol. 2: *Plan Concept, Policy and Regulations,* (1979), pp. 3-9.

[3]The actual process may vary among municipalities. For example, the ERPC has authority for subdivision approval in all municipalities in the Region except St. Albert and the City of Edmonton. The concern is with the process used in the City of Edmonton.

[4]This distinction is made by R. Barras and T.A. Broadbent, "The Analysis in English Structure Plans," *Urban Studies* 16 (February 1979), pp. 1-18. The classification is the essence of new development planning.

[5]Ibid., *Regional Plan,* Vol. 2, Appendix B.

[6]Ibid., pp. 2-2.

[7]Ibid.

[8]The factors include:
(a) existing land use
(b) land use commitments
(c) the nature and intent of individual land classes
(d) priorities established or implied by commission policies
(e) projected land requirements for individual classes and their dominant uses. (Ibid., Regional Plan, Vol. 2, Appendix B-2.0.)

[9]Refer to Appendix B below for a discussion of various purposes of models.

[10]For the purpose and permitted use of each classification see Ibid., *Regional Plan,* Part III.

[11]See Ibid., Appendix B-4.0

[12]Ibid., Vol. 1: *Introduction and Characteristics,* (1978), pp. 56-57.

[13]Ibid., Vol. 2: *Plan Concept, Policy and Regulations,* (1979), Appendix B-6.0

[14]It is important to note that the ratios were made from 1971 data and taken from Alberta Department of Municipal Affairs, Provincial Planning Branch, *An Urban Land Use Analysis of Selected Alberta Communities,* (1971).

[15]City of Edmonton, Planning Department, *Edmonton General Municipal Plan,* 2 Vols., Vol. 1: *Bylaw 6000* (April, 1980); Vol. 2: *Policy Reports,* (April, 1980).

[16]Additional information was obtained from: City of Edmonton, Planning Department, *Edmonton General Plan Workshop Papers,* 10 Vols. (March, 1979); Interview with Mike Kubasiewicz, General Research Section, Planning Department, City of Edmonton, Edmonton, Alberta, 26 March 1980. Mike Kubasiewicz did the forecasting component of the General Plan.

[17]Planning Department, *Edmonton General Municipal Plan,* p. 4.

[18]Planning Department, *Edmonton General Plan Workshop Papers,* 10 Vols., foreward.

[19]This methodology differs from that report in Ibid., *Workshop Papers,* Vol. 3, pp. 8-14. The actual methodology used was obtained from the interview with Mike Kubasiewicz, 26 March 1980.

[20]With minor ad hoc alterations, the City used the projections of William Graham Consultants, Western Realesearch Corporation Ltd., *Canadian Pacific Rail Relocation Study; Urban Development Component, Phase One, Working Papers,* (1977).

[21]The precise form or independent variables of the regression analysis were not presented. See Ibid., *Relocation Study,* Appendix 2, pp. 155-66.

[22]A specific form and process of combining the two methods was not identified. One can assume that it was made by staff judgements.

[23]Refer to Ibid., *Workshop Papers,* Vol. 7-10.

CHAPTER III

LAND USE MODELS

This chapter analyzes a number of models the ERPC could use in their plan design function. These particular models were chosen for the following reasons.

First, the size of the region and the nature of the problems indicate that urban land use models are required. In this study, the size of the region is administratively defined by the ERPC boundaries. The Region is small relative to a regional classification such as Alberta or the Canadian West; thus, more of an urban region. The major land form in the Region is urban. Therefore, the appropriate type of models to study this region would be urban models. Also, the nature of the ERPC problems are essentially related to land use; something which urban models focus on.

Second, an attempt was made to cover models built for any purpose; but one that could assist in the plan design in some way. Models can be classified as *market analysis* or *planning:* refer to Appendix B. The market analysis models are largely used as inputs into the plan design. As discussed below, they have a number of sub-classes. Within this class, *descriptive* models give planners an understanding of the behaviour of the complex system under study. *Prediction* (policy analysis) and *impact* models educate planners and allow sensitivity testing of possible alternate states of the world. *Estimation* models indicate what the state of the world would

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be without any major policy changes or impacts. Or, alternatively, they are comprehensive enough to include many policy and impact changes from the input side. Through these types of models, the planner gathers information. Along with the objectives, the information is used as inputs into the plan design. These are generally *positive* models; however, normative micro behaviour can be assumed to make projections. On the otherhand, planning models are *normative*. They can be used as inputs to or completely do the planning design functions. The ultimate purpose of this thesis is to recommend a model which will assist planners in their planning design function. As such, models used for any of the above purposes can be used in conjunction. They are not mutually exclusive. All types are considered in the discussion below. Considering the complexity and multiple objectives of the Regional Plan and the limited application policy and impact models, an estimation model is preferred. Policy and impact analysis are certainly useful but the model has to be sufficiently comprehensive in these applications to give a complete sensitized view of the future state of the world. As discussed below, a policy or impact model that is capable of a large number of policy or impact simulations may become too comprehensive and too complex to be operational.

Third, the models analyzed come from various approaches to modeling. The normative models include the highly theoretically elegant and analytic New Urban Economics and Mill's highly theoretical but empirical, linear-programming model. The remaining can be classified as *simulative* models. They are positive models and include the simple, operational Lowry Model through to the realistic and complex MIT.

Fourth, they all have been or have the potential to be operational.

Fifth, they are comprehensive in dealing with all land uses in a single model.

3.1 The New Urban Economics[1,2]

The new urban economic models (NUE) are direct descendants of the classical spatial equilibrium models.[3] The NUE models are, however, general equilibrium models with equilibrium in three or four sectors: production, consumption, transportation or housing. The seminal work was done by Mills, with a utility maximization framework, and Beckmann with a production function framework.[4] There are many variants of NUE but all generally start with specifying the functions, maximizing it, deriving the first order conditions and from there solving the model. The solutions are generally qualitative, in the form of negative rent or density gradients. A number of assumptions about the nature of urban phenomena are necessary to allow the use of continuous models and mathematical methods. These assumptions are discussed below.[5]

The assumptions vary from model to model. The models are set up on the assumptions and researchers relax and vary assumptions to observe alternate solutions. The "standard" or "basic" models' assumptions are discussed below.

First, NUE models assume a one-dimensional city. The city is circular with the possibility of transportation in all directions. The city can be described by a linear ray from the Central Business District (CBD) to the urban boundary. Therefore, the models deal in one-dimensional space as opposed to discrete areal zones. The reason is that the mathematical tools of analysis require smooth differentiable functions. This assumption rules out discontinuities in rent and density gradients.

Second, a corollary to the first, is the assumption of a monocentric city, that is, all work takes place in the centre of the city. This assumption has been relaxed but not without added complexity to the solution. Unless the secondary centres take the shape of annular rings, they cannot be handled via a one-dimensional analysis.

Third, exclusive zoning for production and residences is assumed. Production takes place in the CBD. Residences are located in a ring around it. Transportation is also located in the residential ring. Residences are not located in the CBD and production is not located in the residential ring. This assumption rules out competition between non-residential land uses and residential land use. This is, of course, unrealistic and becoming increasingly so as decentalization is increased. It is questionable whether this was ever valid as 19th Century cities exhibited mixed land uses.[6]

Fourth, production is neglected. Production is a single sector producing the composite consumption good in the CBD. Earlier models treated the CBD as a point, thus, having no land use. Later models treated it with a finite radius, but still producing one product and having no other land uses. Employment is determined exogeneously. This creates a problem as a major reason for the existence of cities is agglomeration economies. Some progress has been made with relaxing this assumption, however, the production sector and the CBD still have been given less emphasis than housing and transport in the residential ring.

Fifth, transportation carries people only. The purpose of the transportation system is to move commuters from the residential ring to the edge of the CBD. The mass transit is laid out in a network of radial roads from the CBD. Transportation is, however, ubiquitous from the linear ray

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assumptions. Thus, the transportation network would have to be very dense. This, of course, is unrealistic. Transportation demand is usually treated as the number of commuters times the average road-width per commuter. Thus, transportation land competes with residential land in the residential ring.

Sixth, a number of homogeneity assumptions are represented in the model. Land is assumed the same quality everywhere. Production is one sector. All houses are the same although plot sizes increase with distance from the CBD. All residents are assumed to have equal preferences.

Seventh, the public sector is ignored. The public sector can affect the allocation through the many types of land use controls, urban renewal, infrastructure, taxes, and land holdings. The reason is that the objectives and behavior of the public sector are difficult to include in the neoclassical competitive-equilibrium models.

Eighth, implicit in NUE models is that competitive bidding determines land use, however, competition is only between housing and roads in the residential ring. Exclusive zoning rules out competition between residential and non-residential land uses. This is unrealistic as road development is a public sector decision. The public sector is almost unconcerned with price because of their power of eminent domain. Road or land use is generally bought below market price. The power of non-residential activities outbid residential activities is a major factor in land use conversions. Because non-residential activities are determined exogeneously and placed in the CBD, the implicit assumption of competitive bidding is not valid.

In addition, the constraints which operate on the urban land market are ignored. First, lag and adjustment factors are not considered because

of the long-run equilibrium assumption of NUE models. Second, the homogeneity assumptions make the competitive process appear more efficient. The exogeneous specification of non-residential activities in the CBD gives an efficient allocation. One might argue that this is the same result as competitive bidding because business activities have a greater need for accessibility and greater capacity to outbid residences. Therefore, they would occupy the CBD through competitive bidding. A similar argument holds for households. Households are heterogeneous with respect to other things besides income: tastes, race, etc. Also, neighbourhoods and housing types are heterogeneous. These factors will result in discontinous rent and density gradients. Finally, rent discontinuities and density variations are caused by the planning authority's regulations on floor area ratios, zoning, building codes, and determination of public infrastructure. These factors cannot be taken into consideration in the continuous neoclassical models. In sum in the NUE models, the market, by assumption, appears to operate more efficiently than in reality.

Finally, NUE models can be criticized for their static long-run equilibrium nature. Time can only be considered if one varies the parameters as in a comparative static framework. It is questionable whether the long-run spacial equilibrium is attainable and the adjustment path towards equilibrium seems the more appropriate analysis.

3.1.1 Summary

NUE models are highly theoretical land use models. High quality theoretical models are simple generalizations of the real world. The departure from reality is indicated by the above assumptions. However, if

the theory (as represented by a negative rent gradient) cannot be universally applied, as stated above, then the validity and reliability of the theory is questionable. The simplifications would not be a drawback if they were made to formulate a testable model and tests carried out. No such tests have been carried out. Rather, numerical solutions have been derived and compared with other predictions and empirical evidence. However, the predictions are too general; a negative rent gradient for example. Detailed planning applications require solutions over time and two or three dimensional space, whereas, NUE have only one dimension and do not include time. In addition, most of the analysis is qualitative and forecasting is limited to sensitivity analysis with exogeneously specified parametric changes. The result is in orders of magnitude only. Thus, the growth of activities is exogeneously specified and only the allocation determined by the model. In terms of policy applications, each model is specified to analyze a specific problem. The models are inflexible and a new one has to be built to analyze a different problem. As such, NUE models can be of little usefulness in forecasting for planners and policy-makers. NUE assumes narrow micro responses of an "economic man" where more complex behavioral responses are more relevant. Also, the nature of the land market is not as efficient as NUE presumes.

The NUE theories and continuous models may not be the most appropriate for urban forecasting. A linear-programming approach, discussed next, does not have some of the NUE's inherent problems.

3.2 Mill's Linear-Programming Model[7]

The model can be described as *general, static,* and *equilibrium. Optimizing* behaviour on a *macro* scale is modeled. It can be considered as

a *planning* model with market analysis interpretations. The equations are *linear*. The system is solved *simultaneously* and the solution is *analytical*.

As with NUE, this model uses optimization techniques for its solution. But in this case, the solution technique is not analytical but linear programming. This allows the city to be treated in discrete rather than continuous manner. The simplified view of the world with the unrealistic assumptions are still required. They include: the city is a homogeneous plain; all goods are imported into and exported from a predetermined single point, placed at the city centre; the same types and amounts of activities take place in all squares that are equally distant from the city centre; the city is divided in a grid, where traffic moves in a north, south, east and west direction and through each square's centre; r export goods are produced in the city and exported whereas one good housing (can be interpreted to include other locally produced goods and services) is consumed by city residences; and goods are transported by one transport mode.

The purpose of the model is to analyze the efficiency of market resource allocation in urban areas. In the model, the production of export goods by various activities are represented by land intensity input-output coefficients. The coefficients represent the amount of each input (land, labour, capital) required per unit of a particular output using a specific activity. An activity, say, S is defined as the production of a unit of output in a five-storey building. Thus, the land coefficient would be small for a large value of S; since less land is needed per unit of output in a ten-storey than a five-storey building. Respectively, the capital coefficient is large for a large value of S. Labour coefficients are

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independent of building heights. Thus, unit production costs may change with relative factor costs and building height. The specification of technology in this manner allows economies (and diseconomies) to be dealt with in a linear-programming framework. Also, transportation congestion is represented by a transportation cost function rising in a stepwise manner. The objective function minimizes resources (land, labour, capital) and transportation required to produce a predetermined level of exports. The constraints ensure: total production of each good is at least as much as that exported; housing production is sufficient to house all city workers; workers do not commute away from the city centre; the capacity of transportation depends on the resources devoted to it and the congestion levels (measured by narrower roads) tolerated; and land used for production and transportation does not exceed available land in any square. The output of the model gives the optimum amount and location of production for the export goods and housing, the optimum resources devoted to transportation, and the optimum congestion levels. The result is a typical neo-classical city with a negative rent and density gradient.

Mill's model analyzes the efficient allocation of resources of which transportation (provided by the public sector) is the key. He explores the issue of public intervention in the market and concludes that the market will efficiently allocate resources if transportation is efficiently priced. The policies this model could analyze would include land pricing, land taxation, transportation pricing, and land use controls.

Relative to NUE, this linear-programming framework has some interesting advantages. Mainly, it sacrifices some theoretical purity for realism. Specifically, it allows the city to be dealt with in two dimension space in a nontrivial way. Exclusive zoning for production and

residences is not assumed. Production is not neglected. The transportation system carries people and goods. The results are empirical, however, order of magnitude analysis is still more appropriate. Finally, it is a general framework where institutional constraints can be included.

On the other hand, the model still has some drawbacks. With slight variations in input-output coefficients and transport costs, the city changes from one extreme (little commuting, with most employment in residential zones) to another (heavy commuting, low shipments of goods, and separation of residential and production zones). On the other hand, the optimal level of transport congestion is insensitive to parameter changes.[8] The model has an allocation function only, with the level of production given exogenously as export goods. It is limited to specific policy applications. Thus, its usefulness in plan making is limited given the high cost of data collection and uncomprehensiveness in policy or impact analysis. Political input is restricted to negative policies. It is concerned with the narrow assumptions of "economic man". However, in trying to achieve more realism it also sacrificed greater complexity in the solution procedure. This is a drawback because policy-makers must understand the model before they will have faith in its results. The unrealistic assumptions of a monocentric city and a unimodal transportation system still remain. Attempts to deal with these and other assumptions would increase the complexity of model. Finally, as the model attempts to include these factors and a more comprehensive output, the feasibility of obtaining solutions decreases.

The greater complexity of the real world can be handled better through large-scale simulation models than the NUE or the linear-programming type. These models are discussed in the following section.

3.3 Simulation Land-Use Models

Characteristic of most of these models is the division of the urban space into a large number of small zones. Activities are forecasted and allocated to zones in an attempt to simulate the urban space. The *Lowry Model,* one of the earliest models, has had widespread applications and proved useful to planners and policy-makers.[9] The success of the model is based on its meaningful results, simple structure of its casual relationships, and potential for expansion of the original framework.[10] For these reasons, an explicit and full representation will be given below. Other models, because problems with their complexity and huge data requirements made them unoperational, will only be summarized.

3.3.1 Spatial Interaction Models: The Lowry Model

In 1962-63, Ira S. Lowry developed the seminal spatial interaction, comprehensive land-use model for the Pittsburgh Comprehensive Renewal Program.[11] Lowry's original framework became the foundation for subsequent interaction models.

The model is a *market analysis* model. The model can be classified as *general* and *non-optimizing*. The treatment of time is *static* and an *equilibrium* in land, employment and population over space is assumed to exist in the final output. The sub-models are *strongly-coupled*. *Linear* equations are found in the model. The model has *simultaneous* relationships but is solved *sequentially*. In essence, it is a *simulation* of urban geography as it grows. This aspect of Lowry's model is often referred to as creating "instant metropolis".

<u>3.3.1.1 The Theory</u>. Lowry's primary purpose was operationality which left the model theoretically weak. The model is built on an "export-base" theory (of sorts) for the generative function and two "gravity" models for the allocation function.

The model simulates urban growth as follows. Given the spatial distribution of "basic" employment, households are assumed to locate in proximity to the basic workplaces. "Retail" activities and, thus, retail employment locate in proximity to serve the households. The retail employment generates more population, the new population demanding services, and so on. The basic employment-population-retail employment relationships and, thus, basic employment-total employment multiplier gives the model a quasi export-base appearance. The difference lies in the definition of export and retail employment. Lowry defines basic employment as being employed in industries

> ...whose clients are predominantly non-local. These 'export' industries are relatively unconstrained in local site-selection by problems of access to local markets and their employment levels are treated as primarily dependent on events outside the local economy.[12]

Retail employees are defined as those working for companies and establishments "...which deal predominantly and directly with the local residential population."[13] By these definitions industries who are exporters export all their goods. This is a theoretically correct application but wrong technically as a portion of many export industry's output is consumed locally. In Lowry's original work, however, basic employment is calculated as the residual after retail employment has been calculated. The problem is that basic employment did include industries which produce intermediate commodities for retail industries. This would bias the multiplier downwards. There is no direct connection between

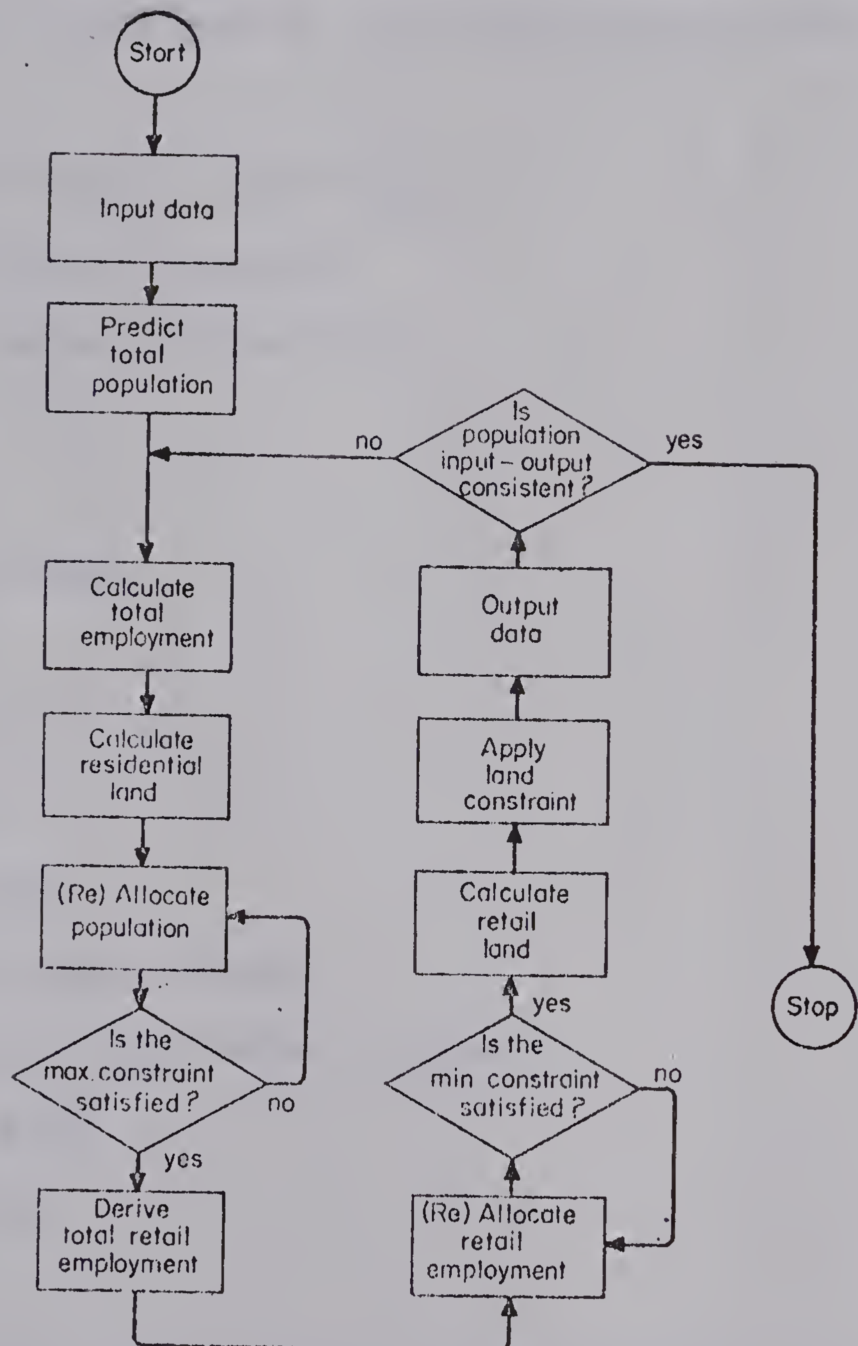
export and service industries; only via population. Lowry was never under the illusion that he used an export-base model. In fact, he used the terms *basic* and *retail* for convenience and suggests *site-oriented* and *residence-oriented* are more precise. Also, his concern was more with allocating than generating regional employment and population.

Another problem with the generative part is treating all basic activities as a single industry. This ignores differences to industries in terms of agglomeration economics, transport costs, and rent savings. Since all basic employment is exogeneous these locational aspects of basic employment are ignored.

The allocation function is achieved by two spatial interaction models or rather *potential functions* of the *gravity* type. A spatial interaction model measures the flow of activities between areas whereas Lowry's potential function measures the sum of all activity flow into each area. The theory comes from the area of social physics. The gravity theory is a simple hypothesis that the attraction between any two masses is directly proportional to the product of the two masses and inversely proportional to their spatial distance. The allocation function is, thus, theoretically weak depending on statistical regularities of mass behavior. Lowry justified this by improving on the operationality of the model: "a gravity model promised to be much easier to build and cheaper to operate."[14] The potential functions may improve the operationality of it but they are poor demand functions.

3.3.1.2 The Model. The operation of the model is illustrated in Figure 2. The model consists of nine simultaneous equations and three inequalities. In the system the number of independent equations equal the

FIGURE 2: The Lowry Model



Source: Benjamin Reif, *Models in Urban and Regional Planning,* (London: Leonard Hill Books, 1973), p. 186.

number of unkowns, however, with the addition of three inequalities as constraints a solution cannot be guaranteed. The best solution procedure, therefore, is an iterative one. To follow the accepted procedure and for illustrative purposes Lowry's iterative solution and much of the same notation will be used in this text.[15] The following notation will be used:

Variables

A = area of land (thousand square feet)

E = employment (number of persons)

P = population (number of households)

C = trip cost

Z = constraints

Superscripts and Subscripts

U = unusable land

B = basic sector

R = retail sector

H = household sector

R = retail establishment category

M = number of retail establishment categories

i, j = areas or zones

N = number of zones,

Constants

f = inverse activity rate (1/number of persons employed per household)

a^K = retail employment-population coefficients (E^{RA}/P)

c^H, d^K = home and work based shopping trip weight factors

e^R = retail employment density ratio

z^H = density constraint (maximum households per acre)

z^{RK} = employment constraint (minimum number of employees)

Functions

f_H, f_K = decreasing functions of travel cost from work to home and from home to retail stores

Values for constants and functions are determined by estimation outside the model or calibration procedures. In addition, values for A_j, A_j^u, A_j^B, E_j^B and c_{ij} are given. The model is comprised of the following equations:

Land Use

$$A_j^H = A_j - A_j^U - A_j^B - A_j^R$$

Household Sector

$$P = f \sum_{j=1}^{N} E_j \qquad (2)$$

$$P_j = g \sum_{i=1}^{N} E_i \quad f_H (c_{ij}) \qquad (3)$$

Equation (3) is the first interaction model. The normalization factor, g, ensures that:

$$P = \sum_{j=1}^{N} P_j, \qquad (4)$$

and is calculated by substituting equation (3) into equation (4) and solving for g. The population allocation procedure starts by setting A_j^R = o and exogeneously determined E_i^B to E_j. A_j^H is obtained from equation (1). P can be calculated from equation (2), however, in order to to speed conergence the employment multiplier $(1 - f \sum_{j=1}^{N} a^K)$ can be calculated outside the model and included; therefore equation (2) becomes:

$$P = f \frac{E}{1-f \sum_{j=1}^{N} a^K} \qquad (2a)$$

E in equation (3), however, still uses E in the first outer iteration. The population is allocated to zones according to its potential. Each zone's

potential is compared against that zone's density constraint.

$$P_j \leq Z^H \; A_j H \qquad (5)$$

The population of all zones violating this constraint is set equal to the constraint. The excess population from these zones is aggregated and then used to recalculate g. The excess population is re-allocated and, if there is an excess, g calculated again, and so on.

Each retail sector employment is calculated by,

$$E^{RK} = a^K \; P \qquad (6)$$

and then allocated by the second spatial interaction model

$$E_j^{RK} = b^K \left[C^K \sum_{j=1}^{N} P_i f_K(c_{ii}) + d^K E_j \right] \qquad (7)$$

Where b is calculated to ensure that

$$E^K = \sum_{j=1}^{N} E_j^K \qquad (8)$$

Then, as in the first model, the E_j^Ks are adjusted to ensure that

$$E_j^K > Z^{RK} \qquad (9)$$

For each zone where $E_j^K \leq Z^{RK}$ that zone's E_j^K is set to zero the surplus fed back into equation (7) for the areas adjacent to zones not meeting the constraint. The iteration continues until all the E^{RK}s are allocated.

Total employment is given by

$$E_j = E_j^B + \sum_{K=1}^{M} E_j^{RK} \qquad (10)$$

The amount of retail land required is calculated by

$$A_j^R = \sum_{K=1}^{M} e^K E_j^{RK} \qquad (11)$$

and adjusted to ensure that

$$A_j^R = A_j - A_j^u - A_j^B \qquad (12)$$

where the right-hand term is the actual amount of land available for retail purposes. If $A_j^R > A_j - A_j^u - A_j^B$ then set $A_j^R = A_j - A_j^u - A_j^B$, and for the first outer iteration overcrowding is allowed.

The second outer iteration starts by entering A_j^R from equation (12) and E_j^{RK} from equation (7) back into equation (1) and (2), respectively; and continues through to equation (12). A^R now having a positive value will displace, via the density constraint, land available for housing and eventually eliminate the retail overcrowding. Lowry assumes that retailers will outbid households for space. The solution procedure continually feeds in retail employment and retail land-use until the population is distributed and, thus, all variables stabilize.

<u>3.3.1.3 Summary</u>. The advantages of the Lowry model include its simple structure, economies in data requirements, consistency in different types of land use and, thus, its usefulness in practical applications.

Some of the disadvantages have been noted above. Accessibility relationships based on empirical regularities are poor demand functions. Their reliability is short-term at best; but the model is a long-term equilibrium model. In assuming an economic base theory, the technical problem of determining the proper amount of basic and service employment has been noted above. Given the struture of the model, it is doubtful whether it can ever be rationalized as having an export-base structure; there is no direct relationship between the export and service industries.[16]

Lowry used one classification for basic industries, and neighbourhood, local and metropolitan classes for service industries. These broad classifications assist in the operationality by defining aggregated amounts

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of employment per zone. More detailed classification, however, would assist planners in identifying site sizes and service specified to each industry.

The model can be used only for impact and prediction; impacts of new industries and policy analysis on transportation, residential and service location by zones and interzonal trip distributions. The usefulness for impact of government expenditures is limited. The problem with using it for estimation is specifying the location of the export industries. This may not be difficult for one or a few industries in a small region. However, in a large region, the small differences in transportation costs among locations within a region, the dynamics of the land market and political approval make this difficult. For estimation, a large number of basic industries over a long period of time have to be estimated by zone making the Lowry model's usefulness in estimation even more remote.

The following sections briefly discusses models which use more theory and realism in their representations. The models consist of a large number of equations and interrelations. The structures do not exhibit any distinguishable pattern. Also, neither of the following models are presently in operation. For these reasons they are given only cursory attention.

3.3.2 The Penn Jersey Model

The Penn Jersey model was the most ambitious effort of its time.[17] The primary goal of the Penn Jersey Transportation Study was to provide a simulation model which would provide predictions of location and land use under differing land use and transportation policies. The secondary goal was to use sophisticated mathematical models along with the scientific

method of disproving assumptions in order to come closer to simulating the actual operation of the urban system.[18] This second aspiration according to the author was "quite naive."

Originally, the researchers built sub-models which attempted to explain residential, service and manufacturing location on the micro level. The development of the Herbert-Stevens Model of residential location came out of this process.[19] The Herbert-Stevens Model is a linear programming model. Residential activity is allocated to maximize rent-paying ability. Rent-paying ability is defined as the difference between budget allocated to households to purchase a housing bundle and the cost of that bundle (excluding site costs). The model optimizes the location of different classes of households subject to capacity constraints on land and a given number of households in each group. Similar attempts were made to model the economic behavior of firms; a theoretical or model description was not given. Attempts to operationalize either the household or firm sub-models were unsuccessful because of data limitations.[20] The researchers then turned to modelling the aggregate behavior using regression analysis. The model can project to any time period using five year intervals.

The model's primary generative sub-model is a cohort survival model. A cohort survival model projects population using estimates of birth, death and net migration rates. The cohort survival model is directly connected to regional employment and regional income distribution sub-models. This means that growth is largely explained by population growth (via age-sex economic activity rates) with no economic growth feedbacks to affect population growth. A linear regression model is used to allocate employment to various sectors.

The purpose of the income distribution sub-model is to allocate population to income groups. Historically, percentages of population in different income categories has remained relatively constant. Thus, they assume a constant distribution around the medium income. Projections are then made by assuming a certain increase in medium income.

The residential location sub-model allocates people to zones by the zones share of population growth and immigration. Migration from i to j takes place only if the sum of value of independent variables in j is greater than i. The variables include the proportion of population of j in the higher income groups at the beginning of the period, the net residential density, a weighted sum of accessibility measures, the proportion of land available for residential use at the beginning of the period and the proportion of land in economic use. The next sub-model allocates population to residential land use. That is, it calculates the amount of residential land consumed per household. This part has the Alonso type framework. The amount is a function of income minus transport costs, the position of the urban fringe and accessibility measures.

The manufacturing employment sub-model has the same form as the residential location sub-model. The manufacturing land use sub-model uses trends of the previous years employment. Service employment location in each zone is determined by a spatial interaction model given initial estimates of total population and total employment. Service land use is determined in the same way as manufacturing land use. For certain industries, their location and land use are determined outside the model and used as input into the model. Street land use is calculated as the residual.

A series of constraints and checking procedures realocate land uses to ensure density constraints are not violated. In terms of conflicting uses, retail and service are given first priority, then manufacturing, then residential.

3.3.2.1 Summary. The model's generative function is weak as it assumes most growth is a function of population growth. The forecasting capabilities are, thus, limited. The model's structure is complex with many equations and sub-models. Political input is limited to negative constraints. The residential land is allocated on the basis of competitive bidding. However, there is no competition between residential and non-residential land use. The initial attempts of simulating economic behaviour failed due to data problems. The final operational model has also not been used to any great extent.[21] One would expect that the heavy data requirements are a major deterrant.

3.3.3 Massachusetts Institute of Technology Econometric Simulation Model

The MIT model is the most realistic attempt to simulate the urban environment.[22] The model's structure includes relationships reflecting the behaviour of households, business, and government; although the urban government part in the allocation sub-model was never built.[23] The primary purpose of the model is to permit evaluation of policy alternatives of national, regional, metropolitan and local governments.

The MIT model consists of three sub-models. The macroeconomic model is a variant of the export-base model. Given population, capital stock, technology, export demand, wages, prices and unemployment, it generates output employment and income distribution, and changes in wages and

prices. The second sub-model is an adjustment model. It forecasts changes in population and investment and, from this, provides population and captial-stock inputs into the macroeconomic model. These two sub-models provide metropolitan growth input into the spatial-allocation sub-model. The spatial-allocation sub-model attempts to consider the following factors: colocation, which is the locational interdependencies in scale and type of other activities either in proximity or accessible to other areas; durability and specialization of urban captial structures; inefficient land market caused by imperfect knowledge, long-term leases, costs of relocation, speculation, etc.; the public sector with taxes and expenditures, land use controls, and being a major land user. The allocation is on the metropolitan level with each zone corresponding to a political jurisdiction. Large cities are disaggregated into several zones.

The MIT researchers had attempted to add much realism in their model: a major role for governments with positive and negative policies; locational interdependencies; constraints on the competitive process; and durability of capital. Unfortunately, there is a gap between what is feasible and what is desirable. As the authors explain,

> ...we have collected most of the data that will be needed for preliminary versions of the model and some equations have been estimated. Undoubtedly, many compromises will have to be made between our plans and what turns out to be feasible.[24]

It appears that the operationality problems were never worked out.[25] Finally, the model is a short-term model when most regional problems are long-term.

3.3.4 Inter-Institutional Policy Simulator

The Inter-Institutional Policy Simulator (IIPS) was initiated in the late 1960's for the Vancouver area.[26] The model primarily focuses on

[illegible]

housing land uses. The structure of the model is under continual revision. It is included in this section because of its "useful" and somewhat unique approach to model building. Also, it represents a Canadian experience in model building for regional planning.

The unique approach can be described by the model's two goals: synthesis and usability.[27] The synthesis goal is centered around including interdisciplinary methodologies and inter-institutional research. The objective of the synthesis goal is to include in the model building the theory from the academic institutions, the experience from public and private institutions, and from everyone the requirements for the model to be useful. Even some of the more applied university research has not transported into decision-making processes of public and private decision-makers. Also, some of the intuitive and experiential knowledge of these decision-makers has not been given to researchers so their models can reflect more of the reality of the world. Clearly, the results of a model can gain from a synthesis of practical and theoretical input.

The developers of the model felt the model should be "useful", "usable", and "used". In being useful, it should be capable of analyzing those concerns decision-makers actually have. Economic to run, accessible, and easy to understand and operate would make it usable. It would be used if government officials and citizens at large did not have to rely on the results of a large "block box" they did not understand.

As a result of these goals, the model builders adopted a process-oriented approach as opposed to a product-oriented one. That is, they were not directed to a specific end product (the final model) but were directed towards a process of continually adopting the model. Thus, they started

with simple, loosely-coupled sub-models. Flexibility was maintained at all times. Sub-models were continually improved upon but with the constraint of usability.

The project was initiated by the University of British Columbia, various departments of the City of Vancouver, and the Greater Vancouver Regional District. Later, the Province of British Columbia and Government of Canada provided additional funding. Along with citizens, the various institutions provided the synthesis and feedback on usability.

Initially, the model had eight sub-models: population and demographic, economic, transportation, land use, health systems, pollution, and human ecology sub-models. Initially, all land uses in 82 traffic zones (ultimately 150-200 census tracts) were to be forecasted. Most of the model developments, however, have been with residential land uses only.[28] These models and the linkages between them are under continual revision. It is important to note that the economic model has an input-output base.

To summarize, the model's generative function is quite reliable relative to more simplistic approaches. The model's structure is not complex. Political input is assured. Operationality for all land uses has not been achieved. The reason is the complexity and data problems of allocating all land uses to a large number of zones. The model is successful in some of its uses; depending on the use and on the adaption of the model to provide realistic solutions. For a regional plan model, however, it has three important drawbacks: (1) it does not consider all land uses simultaneously; (2) it does not have an optimality criterion; and (3) because of (1) and (2), it can not determine what is the most efficient allocation of land.

3.4 Summary

This section reviewed a number of alternate approaches to modelling the urban structure. The approaches ranged from the highly theoretical NUE, to the practical Lowry, and to the "realistic" MIT simulation model. All had their drawbacks for use as a forecasting tool in planning land uses. The NUE models generally lack a generative function and the output is too general for forecasting uses. The Lowry model is more suited for impact analysis as it depends on exogeneously specified locations of export industries. MIT was not operational because of formulation and data problems. The question then becomes: are land use models, per se, the most useful approach to assist regional and local authorities in planning for the growth? Land use models are differentiated from applications of macroeconomic models by the former's concern primarily with allocation of activities and the latter's concern with the generation of activities. The argument presented below suggests that they are not.

First, one must consider the complexities of the allocation process the models are trying to accurately represent. Th political input whether through stimulating the economy or restricting growth cannot be forecasted on a small sub-area basis. The various sociological phenomena that affects behavioral patterns increases the complexity. Finally, the dynamics of the land market (long-term leases, collocation, relocation costs, price expectations, etc.) further complicates the process. These add to the data requirements, already heavy from the many zones and several land use categories. In the United States, during the 60's, development of many of the sophisticated land use models were stopped because of problems related to obtaining data.[29] In particular, builders were unaware of the data and computer resources needed; and most were too ambitious (trying to be too

comprehensive in the purpose). The projects were abandoned when time and money ran out. The British, on the otherhand, were quite successful with model-building. Their models were highly aggregate; based on simple theories.[30] Given an umlimited budget, data collection is never unfeasible. However, the uses of the model must also be considered before huge data collection for an allocation function is economically feasible or even desirable.

Second, considering the nature of the problem, models are needed more for medium to long-term forecasts on the regional or metropolitan level. At each level of plans, the planner is concerned with two things: forecasting the activities he cannot control and recommending the best policies for those he can control. At the lower levels (zoning and subdivision), the planner has control of the amount and type of activities allocated to the specific areas. At the regional level, he has less control but requires forecasts of activities to stipulate policies for lower level plans.[31] The higher level plans are medium to long-term policy documents, thus, requiring medium to long-term forecasts. The longer the term the more difficult it is to forecast activities by finer sub-areas in the region. Therefore, an allocation function of fine disaggregation is less desirable because of the requirements for longer term forecasts and the difficulty of forecasting by small sub-areas in the long-term.

Third, the incremental nature of the planning process makes large-scale land use models an inefficient forecasting tool for planning. The recommendation for specific land-uses in the higher level plans is very general. This gives lower level plans a certain amount of flexibility. The lower the level of plan the more specific the policies on land uses become. For example, as discussed in Chapter II, a sub-area is set aside

for development or redevelopment by a district outline plan or a neighbourhood outline plan. These plans give general land use recommendations to subdivision plans and zoning. The subdivision or zoning level actually establishes the size and nature of the land use. Given the short-term required to approve these plans, the recent market demand gives the planner an indication of the nature of probable future demand. Given this flexibility and the short-term approval process of lower level plans, a large-scale land-use forecasting model is less efficient than extending recent market trends.

Fourth, related to the third, fixing land uses in the longer term can result in an inefficient final allocation of land uses. If future market conditions are significantly different from expected then an inefficient allocation would have occurred. One might argue that zoning bylaws are changeable and, therefore, a reallocation can occur. On the contrary, zoning bylaws can be considered durable up to a point where the misallocation is so large it pays the developers to go through the risk and expense of rezoning.

In sum, the complexity of the allocation process, the nature of the planning problem and the nature of the planning process tip the forecasting model in favour of not having an extensive allocation function. The broad group of models discussed in this chapter were defined as having more emphasis on allocating activities to sub-areas once the activities have been generated (forecasted) for the area as a whole. The next chapter discusses macroeconomic models. These models emphasize more of the generating of estimates of economic activity in the area as a whole.

Footnotes

[1]The title to this field of urban economics was given by E.S. Mills and J. MacKinnon, "Notes on the New Urban Economics," *Bell Journal of Economics and Management Science,* 4 (Autumn 1973), pp. 593-601.

[2]For reviews see Ibid.; A. Anas and D.D. Dendrinos, "The New Urban Economics: A Brief Survey" in G.J. Papageorgion, ed., *Essays in Mathematical Land Use Theory* (Lexington, Mass.: Lexington Books, D.C. Heath, 1976) pp. 261-275; H.W. Richardson, *The New Urban Economics: and Alternatives* (London: Pion, 1977).

[3]Contributors to the development of the classical theory include: J.H. von Thiinen, *Der Isolierte Staot in Beziehung auf Nationalponomie und Landwirtschaft* (Gustau Fischer, Stuttart) reprint of 1826, as reported in Richardson, *New Urban Economics,* pp. 6-11; R.M. Hurd, *Principles of City Land Values* (New York: The Record and Guide, 1903); W. Alonso, "A Theory of the Urban Land Market," *Papers and Proceedings of the Regional Science Association,* 6 (1960), pp. 149-57; W. Alonso, *Location and Land Use* (Cambridge, Mass.: Harvard University Press, 1964); R.F. Muth, *Cities and Housing* (Chicago: Chicago University Press, 1969); and L. Wingo, *Transportation and Urban Land* (Washington, D.C.: Resources for the Future, 1961).

[4]E.S. Mills, "An Aggregative Model of Resource Allocation in a Metropolitan Area," *American Economic Review Papers,* 57 (1967), pp. 197-210; M.J. Beckmann, "On the Distribution of Urban Rent and Residential Density," *Journal of Economic Theory,* 1 (June 1969), pp. 60-67.

[5]As discussed in Richardson, *The New Urban Economics,* pp. 31-42.

[6]R.L. Fales and L.N. Moses, "Land Use Theory and the Spatial Structure of the Nineteenth Century City," *Papers and Proceedings of the Regional Science Association,* 28 (1972), pp. 49-80.

[7]E.S. Mills, "Market and Efficient Resource Allocation in Urban Areas," *Swedish Journal of Economics,* 74 (March 1972) pp. 100-13.

[8]Richardson, *The New Urban Economics,* pp. 173, 174.

[9]Richardson, *The New Urban Economics,* pp. 181, 236.

[10]M. Batty, "Recent Development in Land Use Modelling: A Review of British Research," *Urban Studies* 9 (June 1972), pp. 151-77.

[11]Published in I.S. Lowry, *A Model of Metropolis,* RM-4035-RC (Santa Monica: Rand Corporation, 1964).

[12]Ibid., pp. 2, 3.

[13]Ibid.

[14]Ibid., p. 23.

[15]In addition, the discussion follows closely the presentation by A.G. Wilson, *Urban and Regional Models in Planning and Geography,* (London: John Witey & Sons, 1974), pp. 220-43.

[16]The problems with the export-base theory as a forecasting tool are discussed below.

[17]The structure of the model is reported in Ibid., pp. 243-56; and D.R. Seidman, "The Construction of an Urban Growth Model," *Plan Report No. 1, Technical Supplement Volume A,* Delaware Valley Regional Planning Commission, Philadelphia, n.d.

[18]Ibid., p.2

[19]J. Herbert and B.H. Stevens, "A Model for the Distribution of Residential Activity in Urban Areas," *Journal of Regional Science,* Vol. 2 (1960), pp. 21-36.

[20]Seidman, *Urban Growth Model,* p. 3.

[21]Wilson, *Urban and Regional Models,* p. 258.

[22]As reported in Richardson, *The New Urban Economics,* p. 194-98; R.F. Engle, et.al., "An Economic Simulation of Intra-Metropolitan Housing Location: Housing Business, Transportation and Local Government," *American Economic Review Papers,* 62 (1972), pp. 87-97.

[23]Ibid., p. 92.

[24]Ibid., pp. 87-88.

[25]Richardson, *The New Urban Economics,* p. 194.

[26]One of the first publications on this model was, Michael A. Goldberg, "Simulation, Synthesis and Urban Public Decision-Making", *Management Science* 20(4) (1973), pp. 629-643. Other documentation includes: M.A. Golberg and J.M. Stander, "Analysis of Output and Policy Applications of an Urban Simulation Model," *Transportation Research Record* 582 (1976), pp. 61-71; M.A. Goldberg and D.A. Ash, "Continued Development of the Vancouver Mode," *Transportation Research Record,* 617 (1977), pp. 55-61; M.A. Goldberg, "Developer Behavior and Urban Growth: Analysis and Synthesis" in L.S. Bourne and J. Hitchcock, eds., *Urban Housing Markets: Recent Directions in Research and Policy* (Toronto: University of Toronto Press, 1977), pp. 181-227.

[27]M.A. Goldberg, "Simulation, Synthesis and Urban Public Decision-Making", pp. 629-630.

[28]M.A. Goldberg, "Developer Behavior", p. 213. Also, at the time of this writing, the operationality of other then residential land uses has not been satisfactory. Interview with M.A. Goldberg, Department of Commerce, University of British Columbia, Vancouver, British Columbia, May 19, 1982.

[29]Lee, "Requiem for Large Scale Models," *Journal of American Institute of Planners* 39 (1973), pp. 163-78; and Batty, "Recent Development in Land Use Modelling".

[30]M. Batty, "Computer Models and Structure Planning," *Town and Country Planning,* 42 (October 1974), pp. 453-456.

[31]For arguments along this line see A. Metcalf and B. Pilgrim, "Land Use Planning in Urban Growth Areas - Evaluation: A Compromise," in A.G. Wilson, ed., *Patterns and Processes in Urban and Regional Systems,* (London: Pion, 1972), pp. 306-15.

CHAPTER IV

REGIONAL MACROECONOMIC MODELS

4.1 A Review of Macroeconomic Frameworks

In the last chapter, it was argued (considering the problem at hand) that it would be more "suitable" for the model to have more of a generative function than an allocative function. The group of models discussed in this chapter are in some sense purely generative models. The purpose of this chapter is to review the different types of macroeconomic models and recommend one approach. The considerations in this review are not directly related to land use but related to the essence of the macroeconomic models themselves. Also, because of the diverse nature of the models, no attempt was made to precisely and explicitly weigh the disadvantages and advantages of each framework against the other frameworks. Rather, most of the disadvantages and advantages of each framework are simply explained; in an attempt to give a complete critique of each framework. The input-output framework, it is argued below, is the most "useful" approach. A number of the advantages over the disadvantages make the input-output approach clearly superior to the other approaches. The next chapter returns more directly to the problem at hand by discussing input-output and land use applications.

Essentially, the application of a macroeconomic model to a region (even in the size concerned here) is the same as the application of a

macroeconomic model to a country. The emphasis is, however, different.[1] First, the spatial aspect must be considered. In the land use models above, the anlaysis was more micro. The models above were concerned with proximity between workplaces, residences, and shopping. In a macroeconomic model, the openness of the urban economy is the spatial concern. That is, the concern is with the degree of interdependence between local and non-local markets and, thus, interdependencies among regions. Second, regional economies are more specialized in production and distribution. Third, local government expenditure are more endogeneously determined than higher levels of government in national economies. Local governments have less types of revenue generating sources. This means local governments are less capable of controlling the urban economy through fiscal expenditures. These factors do not alter the basic models but are important to consider because of their relative importance in the growth of regional economies.

The macroeconomic approaches can be classified into two categories, empirical and theoretical.[2] The empirical frameworks include *extrapolation, ratio-extrapolation,* and *shift and share*. Extrapolation is simply extending previous trends into the future. Ratio-extrapolation assumes regional growth will be proportional to the growth of a larger region or the country. For example, Edmonton Region's growth is proportional to Alberta's growth. Shift and share is a combination of the above two.

The theoretical frameworks include *export-base, resource-base* (neo-classical), *Keynesian,* and *input-output*. Besides differing contexts, the frameworks emphasize different sources for the causes of growth. Economic-base emphasizes exogeneous, demand factors. Resource-base emphasizes endogeneous, supply side factors. Keynesian emphasizes

endogeneous and exogeneous demand factors. I-O, because of its highly disaggregated structure, has the capability of considering all factors. Since these frameworks are familiar methods of economic analyses, only a brief comparative evaluation is given here.

The first consideration is feasibility. The "statistical" frameworks are not considered here. First, one might argue that since the statistical frameworks lack a theoretical base, they are less reliable. That is, one can not presume all the economic phenomena will repeat itself in exactly the same form as it did in the past. Therefore, our predictions would be more reliable if we first understood the causes of future change. Then anticipating changes in those causes, we can predict changes in the events based on assumed casual changes. Second, from an academic point of view, the study of trends, per se, is considered less interesting, by this author, then the study of cause and effect. Finally, because of their simplistic structure they cannot be used for policy and impact analysis.

The neo-classical framework is too aggregated and lacks comprehensiveness. The effects of a wide range of alternate types of policies and government impacts cannot be evaluated with the model. It is best suited for impact analysis. This is also limited to impacts of changes in labour, capital stock, and technology. In addition, it only allows supply side considerations; and of the relevant considerations only a portion could conceptually and practically be included in the model. Finally, the framework requires time series data, something not available in the Edmonton Region. The major advantage is the long run outlook required by the planning problem.

The Keynesian framework, on the otherhand, does not have many of these drawbacks. First, it can consider both external and internal influences on

growth. Second, its highly disaggregated and comprehensive approach increases the accuracy of forecasts and uses of the model. Third, it can be used for government impact and policy analysis. Fourth, it is very flexible such that expected changes in productivity, propensities to consume, and propensities to import, for example, can be introduced. The problems with Keynesian framework include the following. First, it is a short-term forecasting model. Second, the actual data available does not always represent the measurements required by theory, therefore, proxy variables are used. Third, it is a demand side analysis only. Fourth, because of the size and structure of the model, it is not easy to introduce changes. Fifth, time series data are generally used. To conclude, neither the neo-classical or the Keynesian frameworks are feasible because of the requirements of time series data. Even in fairly advanced regions, obtaining sufficient disaggregated data is still a problem.[3]

I-O, on the other hand, does not have the limitations of the neo-classical or Keynesian frameworks and improves on the positive features of the Keynesian. It does not require time series data. I-O is more disaggregated, more flexible and, thus, can analyze a wider range of policies and impacts. Also, I-O is suitable for short and long term forecasts considering supply, demand, internal and external causes. Export-base is feasible but has other problems.

The second consideration is accuracy.[4] Export-base is the most popular framework because of its simple and plausible causal structure, and few implementation problems. For these same reasons, however, it is less accurate than the I-O framework.[5] There are few implementation problems because the export base method generally uses secondary, employment data. This creates, however, a number of technical problems. First, this ignores

differences in industry wage levels. Different wage levels will have different secondary impacts. Second, it ignores unearned income; primarily property income and government transfers. Third, non-survey methods of identifying the service from the basic industries are inaccurate. Finally, the study area is delineated by the boundaries of the published data, not economic or policy boundaries. For forecasting, the I-O table should be built from surveys.[6] Therefore, it will not have these problems.

The simple and plausible causal structure relates to a number of conceptual problems. The conceptual difficulties are largely related to the suppression and aggregation of interdependencies among decision units and groups in the economy. First, the export base models usually assumes a stable propensity to consume and do not easily allow ad hoc adjustments. Second, it assumes a constant proportion of consumption spending that creates local income. Third, it assumes regional growth to be a sole function of changes in exports. This ignores internal factors and relationships that affect growth. Finally, the linkages among basic industries and from service to basic industries are ignored. The aggregation and suppression does not allow the analyst to make the necessary adjustments. I-O does not have these problems because of its highly disaggregated, comprehensive and flexible framework. Intuitively, one would consider it more accurate because of its highly disaggregated component driving the model, ability to forecast growth from all sources, ability to alter the multiplier as required, built in consistency checks, and data obtained from surveys.

The third consideration is the uses to which the model can be put. First, economic-base is best suited for short-term projections and only for changes in exports. Because of the simplistic and aggregated nature of the

typical economic base multiplier, internal factors and relationships in a community that can affect growth are ignored. Since these internal changes are longer-term and will affect the multiplier, it can be argued that economic-base is best suited for short-term impacts.[7] Second, the export-base framework fails to explicitly recognize a region as part of an interregional system. Spatial relations between regions are at the heart of many regional problems. Third, its aggregated and simple exogeneous/endogeneous framework limits the types of policy and impact analysis it can be used for. Finally, the framework does not give a comprehensive description of economic interrelations in the economy. I-O does not have these drawbacks. Its large number of applications are important to policy and impact sensitivity analysis in the plan design, and its feasibility.

To summarize, I-O is recommended for the following reasons:

(1) a good set of social accounts with consistency checks

(2) can display and analyze the interdependence among all sectors in the economy (primary inputs, business, and final demand)

(3) simulates growth from all sources

(4) relatively accurate forecasts

(5) flexible and transparent structure

(6) large number of policy and impact applications, especially with the aid of linear-programming techniques

(7) short, medium and long term forecasting capability.

As indicated above, I-O as a framework has a number of advantages. I-O in a regional context has further advantages.

Regional analysis is different from national analysis because space should enter into consideration. While I-O is essentially spaceless, interregional trade flows are easy to measure and consistent with the

theory. The framework can provide analysis of an industry's markets and inputs at a disaggregated level (by industry and region). This feature as well as showing the structural interdependence would assist in analyzing major locational and regional problems. More specifically, markets and factor input changes could be identified. Also, the region's structural and thus income changes or how to prevent the changes could be identified. Thus, while I-O is essentially non-spatial, it is a good regional analytical tool because it can measure changes in economic structure which, in fact, reflect spatial shifts in economic activity.[8]

The drawbacks to I-O are not critical. First, it takes several years, requires much expertise, and is very expensive to build. However, this must be considered relative to the uses and the absorption of present research costs. Second, in the simple I-O model, the conceptual problems include:

(1) fixed coefficients assume an absence of technological change

(2) assumptions of fixed prices throughout the forecasting period

(3) the inability to explain or deal with interregional competitive forces, that is, migration of industries and people

(4) not allowing input substitution

(5) final demand is exogeneous

(6) not designed to specifically analyze the dynamics of structural change, specifically, disappearing industries, new industries, scale economies, localization economies, urbanization economies, and indivisibilities.

These problems are not critical because adjustments to the simple model or additional analysis can be made to include these factors.[9]

The next section outlines the structure of an I-O framework.

4.2 Structure of an I-0 Model

The urban economy involves a large number of economic establishments and markets trading among themselves and with other geographically defined economies. These interrelationships will affect the level and mix of output, income and employment. The Input-Output (I-0) is a general equilibrium framework offering the detail necessary for description and analysis of these interrelations.[10]

One might distinguish between input-output as a set of accounts and the Leontief input-output theory used in forecasting.[11] The former is necessary for operationality of the latter. As a set of accounts it is a descriptive tool which traces the transactions between buyers and sellers in the urban economy; that is, sales of intermediate goods among producers, sales from producers to final users including government, business (capital formation), households and exports, and industry purchases of primary inputs such as imports and household labour services. Thus, the I-0 framework requires detailed information and, as a result, offers a detailed and useful approach. The accounts are listed in a *transaction table;* refer to figure 3. The accounts are the same as national accounts except the business sector is disaggregated and the interindustry flows shown. The accounts show the simultaneous supply and demand relationships of an economy in equilibrium. The table represents the transactions in the economy over a period of time; usually one year. I-0 being a general equilibrium framework assumes the economy is in equilibrium in that period.

In reference to figure 3, Matrix II can be called the *endogeneous* or *interindustry* matrix. It records the sales flow from sectors at the left

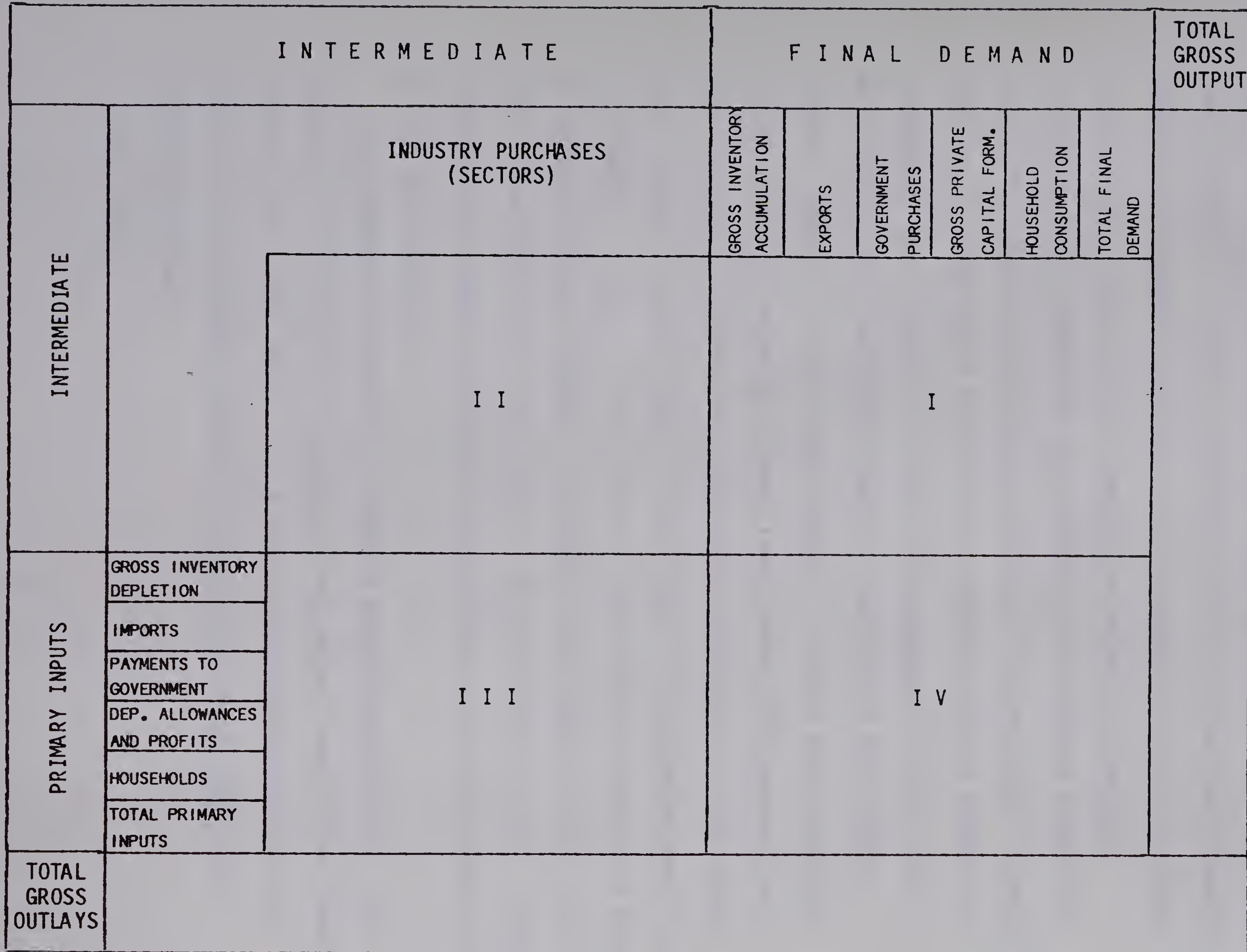


FIGURE 3: Input-Output Transaction Table

to sectors at the top. It is a double entry accounting system, for it shows purchases for final demand and, also, by business for inputs into their production. A sector consists of a group of industries assumed to produce a homogeneous output with similar production or cost functions. Because of the large variety of outputs and differing production techniques, data, compilation and disclosure rule problems hinder the analyst from following the homogeneous output rule precisely. In practice, industries are aggregated by relatively similarily behaved production processes or sales. Matrix I, called the *exogeneous* or *final demand* matrix, shows the sales of each sector on the left to final demand sectors. Matrix IV is the *transfer* matrix. It shows the transactions between the final demand and primary input sectors. The *primary input* matrix, Matrix III, gives the primary input purchases of sectors at the top. By definition each sector's total sales, total purchases and, thus, total output are equal. The value of all final demand purchases is equal to the Gross Regional Product. The value of the primary inputs is equal to total value added which is also equal to Gross Regional Product. The I-O framework is a powerful descriptive tool, however, the concern here is with its use in forecasting.

The essence of Leontief's I-O general equilibrium model is "...the technical relationship that purchases of any sector (except final demand) from any other sector depend, via a linear production function, on the output of the purchasing sector."[12] This can be illustrated by the following equation:

$$X_{ij} = a_{ij}X_j$$

Where

X_{ij} = the value of input of sector i used in the production of output j (transaction table entries, Matrix II);

X_j = the value of output;

a_{ij} = the value of input i to produce one dollar of output j (technical input coefficients).

This assumes that the production functions are *linearly homogeneous*. This also assumes that:

1. since each commodity is assumed to be produced by a single industry by one production method, there can be *no joint products*
2. the linear input functions assumption restricts the functions to *constant returns to scale* and *no substitution between inputs*
3. *additivity,* meaning the total productive effort is the sum of the separate efforts which rules out external economy and diseconomy effects
4. at a given set of prices the system is in *equilibrium*
5. in static I-O models, there are no capacity constraints so that supply of goods are assumed to be *perfectly elastic*

Equilibrium is achieved when each sector's output equals total purchases from that sector. These purchases are determined by the outputs of all sectors including itself. This can be expressed as:

$$X_i - [a_{i1}X_1 + a_{i2}X_2 + \ldots + a_{ii}X_i + \ldots + a_{iN}\, X_N] = Y_i$$

where Y_i is the final demand for sector i. Or in matrix format:

$$X\ (1-a) = Y$$

This represents a set of simultaneous linear relations. Each relation shows the distribution of its output to be a function of the output of the other sectors. The general solution of the system shows the output of any

sector to be attributed to deliveries to final demand. The general solution can be expressed as:

$$X_i = a^1{}_{i1}Y_1 + a^1{}_{i2}Y_2 + \ldots + a^1{}_{ii}Y_i + \ldots + a^1{}_{iN}Y_N$$

Or in matrix format using matrix inversion:

$$X = (1\text{-}a)^{-1}Y$$

To transform the accounting tables into a tool to be used in forecasting involves a number of steps. The first step is to transform the transaction table into a table of *technical* or *direct input* coefficients, $a_{ij}S$. The technical coefficients measure the amount of input required from each sector to produce one dollar's worth of the output of a given sector. Since in equilibrium gross outputs equal gross outlays, the technical coefficients can be calculated by adjusting gross output. The technical coefficients are calculated by subtracting inventory depletion from gross output then dividing the transaction entry of each sectors column by the adjusted gross output for that sector. This gives the direct impact on each sector and each primary input for a dollar's increase in output of each sector.

The next step is to transform the direct coefficient table into one that also includes *indirect* effects. As a result of an increase in demand for a sector's output, that sector will increase demand for inputs from various sectors. Thus, industries selling to that industry will increase their output. The chain reaction continues giving the multiplier impact of a change in output. A further step can be made where the table is transformed to include effects of increased expenditures *induced* by households changes in income. This last step is referred to as *closing* with respect to households.[13] With this last step, the multiplier includes direct, indirect and induced impacts. The transformation of the direct

coefficient matrix to either the direct plus indirect or direct, indirect and induced coefficient matrix can be done by two alternate methods. The first is by iteration. Iterative calculation of secondary effects are made until the effects are minimal. Alternatively, the matrices can be calculated by matrix inversion. The inverted matrix is commonly called the *Leontief inverse*. The coefficients derived by either method predict the value of inputs required of each sector's output to deliver one dollar of output to final demand of a sector. An output multiplier is derived by summing the columns of the Leontief inverse. It gives the direct and indirect (and induced) requirements from all sectors needed to deliver one dollar of a sector's output to final demand. Output multipliers are generally used to indicate the structural interdependence between each sector and the rest of the world. Income multipliers, however, are more often used.

There are two types of income multipliers. The *Type I* multiplier refers to ratio of direct and indirect income changes to the direct income change from a change in the final demand of any sector. The *Type II* multiplier includes direct, indirect and induced income changes. The direct and indirect income change is calculated by multiplying the column entries of the Leontief inverse (households excluded) by the selling sector's household row coefficient from the direct coefficient table. Summing the column gives the income change per sector and summing all the sector's totals gives the aggregate economies income change. The Type I multipliers for each sector are calculated by dividing this direct and indirect income change for each sector by that sector's direct income change. The direct income change is the household row entry in the direct coefficients table. The direct, indirect and induced income change can be

read off the household row coefficient of the Leontief inverse with households included in the endogeneous matrix. The Type II multipliers are determined by dividing this income change by the direct income change. The aggregate economy multipliers can be obtained by summing each sector's direct and indirect (and induced) income change, summing the direct income change, and then dividing the former by the latter.

Employment multipliers can be obtained by a number of methods. One method is to impute values for employment in the transactions matrix using ad hoc methods. Another involves estimating employment production functions.[14] For each sector, employment is regressed on output. The coefficients of this regression are multiplied by the direct and indirect coefficients and the results added across the rows. This gives the direct and indirect employment effects from a change in final demand. The multipliers are calculated by dividing this by the direct employment change (the coefficient of the employment production functions). Induced employment effects can be included by estimating a set of consumption functions and multiplying these coefficients by the employment coefficients. This method can be used only if regional coefficients are available.

Forecasting with the I-O table can be done as follows. The first step is to project final demand. Second, final demand is adjusted by multiplying the projected final demand by a ratio of inventory depletions to final demand in the base year and then subtracting this from the original projected final demand. Third, each row of the direct and indirect (and induced) table of coefficients is multiplied by the corresponding row's adjusted final demand figure. Fourth, the columns are summed and this output sum is placed at the bottom of the direct

coefficient's table. Fifth, each column entry of this table is multiplied by the output sum at the bottom of the column. Sixth, the inventory adjustment subtracted in the first step is then added to the output sum to give total gross output in the forecast year. The result is a new transaction table, showing the flows between inputs, industries and final demand in the year projected. The time period for projections can be any time period. However, considering the implicit assumptions of fixed input coefficients, fixed trade coefficients and unlimited plant capacity, the above paradigm is best suited for short-term forecasts.

Medium (comparative-static) and long-term (dynamic) forecasts can be accomodated by the steps described below.[15] To aid the discussion, a fully dynamic model would take the following form:

$$X = A\ X + C\ X + Y$$

where

X = a vector of sector outputs

Y = a vector of final demands

X = a vector of the rate of change in output for each sector

C = a capital coefficient matrix representing the stock of one sector's output used per unit of output of another industry over a specific time period

A = a matrix of direct input coefficients

Step 1. The regional final demand are projected by its components. The projections should be for every year including the terminal period.

Step 2. The input coefficient matrix (A) is calculated. Up to this point only a static short-term forecast can be made.

Step 3. The regional capital coefficient matrix is estimated. It is important to consider capital investment separately because large increases

in output will require additional plant capacity so that projected changes in final demand will require more intermediate goods and also more investment goods from the relative sectors.

Step 4. Changes in the input coefficient matrix are predicted. The coefficients are expected to change because of relative price changes, product mix variations, technical changes, localization economics, urbanization economics and economics of scale. At this stage, medium term or comparative static projections can be made.

Step 5. Predictions of changes in the capital coefficient matrix are made.

Step 6. The regional and national input coefficient are expected to be different because of differences in productive processes, marketing practices and product mixes. If the above matrix (A) represents the national coefficients then it has to be disaggregated into regional input coefficients and an import coefficient matrix or vector.

Step 7. The imported capital coefficients are estimated. They are combined with the investment effects of C to give total expansion investment requirements. This step identifies productive capacity constraints. It may be useful to do the same procedure for labour to identify labour supply bottlenecks. The appropriate adjustments to the forecast can, thus, be made.

Step 8. The regional trade coefficient are forecasted. This would involve forecasting shifts in the share between imports and local inputs for both intermediate goods (Step 6) and expansion capital (Step 7).

The I-O framework, because of its matrix format, high disaggregation, and comprehensiveness, will allow the analyst to easily make the necessary adjustments for long-term forecasts. From the forecasts, the planners can

determine the future economic activity requiring land but not the most efficient allocation of land to those activities. With the aid of linear programming techniques, however, planners achieve this function. Linear programming will be discussed next.

4.3 Linear Programming, Optimization and Efficiency

I-O is neutral from a policy perspective. With linear programming, however, the I-O is given the normative content many policy and planning applications require. This is especially important to the plan design models discussed in the next chapter.

Linear programming, I-O analysis, and game theory are three branches of linear economics.[16,17] In fact, I-O can be considered a special case of linear programming. I-O's problem is to determine the single set of outputs that is consistent with a predetermined set of final products. Generally, in linear programming, goals and activities are analogous to final products and outputs. The difference from I-O is that in linear programming the set of final products is not known but becomes the object of a goal. In linear programming there are a number of different plans or arrangement of activities that fulfill the goals. The problem is to determine which of these satisfactory plans is best. Linear programming is a mathematical procedure that does just that. Precisely, it is defined as:

> ...the analysis of problems in which a linear function of a number of variables is to be maximized when those variables are subject to a number of restraints in the form of linear inequalities.[18]

Linear programming is different from classical optimization techniques because inequality constraints can be in included. This adds more realism to optimization techniques. More importantly, a number of activities, each requiring a specific relative amount of inputs, can be optimized in one

operation. This enables optimization techniques to be applied to many complex real world problems. Of more importance in this section is the relationship between programming, efficiency and resource allocation.

The planners objective is the efficient allocation of a resource, land. The objective of linear programming (in production applications) and the concept of efficiency are one in the same. In a linear programming production problem, the objective function depends positively on all choice variables (activities). If one of the variables is increased, providing it is not constrained, then the value of the objective function has to rise. If it in fact rises, it was not at a maximum in the first place. The first pattern was feasible but not optimal. Linear programming will continue to search for a pattern of outputs that gives a maximum to the objective function, subject to the resource constraints. At the maximum, the pattern of activity outputs is efficient because some activity outputs cannot increase without either decreasing some other outputs or increasing some resource inputs. This is precisely the definition of efficiency.

This sense of efficiency is purely a "technical" term related to production. That is, resources are allocated to activities according to the state of technology. But, the relative value (objective function weights on the choice variables) each activity contributes to the overall objective is determined outside the model. Specifically, the economic interpretation of the weights are prices. They are set by society's relative preferences for outputs and proportional to marginal rates of substitution. This describes the relationship between the welfare concept of efficiency or, that is, "economic" efficiency and the purely computational technique of linear programming. To elaborate, in the optimal solution, every set of prices will give an efficient pattern of

resources such that there is an array (if not infinity) of efficient solutions, one for every set of prices. Thus, from a welfare prospective, one can say that linear programming will determine the complete set of production patterns, but society will have to decide which pattern is optimal by some other criterian. Linear programming, however, can allow society's preferences to be reflected in the optimal allocation.[19] That is, linear programming can determine the complete set of efficient solutions given a complete set of societal preferences.

Through the concept of efficiency, the relationship between linear programming and a competitive equilibrium can be seen. Economic theory tells us that in perfectly competitive markets, if firms maximize their profits, given positive prices for outputs and inputs, the resulting equilibrium allocation of outputs and inputs will be efficient. Thus, competitive profit maximization by all the individual firms will give an efficient set of inputs and outputs. This is a decentralized atomistic way of determining the efficient set. Linear programming can do exactly the same thing, but from a centralized perspective. Because of the additively and constant returns to scale assumptions, it is irrelevant whether it is profits in the aggregate or individual firms we think of being maximized. This illustrates its usefulness to program and resource planning. That is, linear programming can simulate a competitive market where one does not exist in order to make optimal decisions on resource utilization. Linear programming does this by giving solutions for the optimal allocation of scarce resources. At the same time and perhaps more importantly, the prices of those scarce resources are determined.

These "shadow" prices are determined in the dual of, in this case, the primal linear programming problem, maximizing output.

> Their plain economic meaning is none other than that of marginal value productivity of the productive factors in an optimal situation when all alternative uses have been taken into account. The reason why shadow prices are considered to be important for an economist is that neo-classical theory of resource allocation tells us that the value of the national product at given prices of final commodities is maximized if productive factors are employed so as to equate their value productivities with their rentals.[20]

The dual shadow prices are important tools for planners as discussed in the planning model below.

This concludes a digression from the I-O discussion. The next section outlines a number of approaches to interregional I-O tables.

4.4 Interregional I-O Models

Interregional input-output analysis is essentially an extension of regional input-output analysis. It is used to display and analyze the economic interdependencies between regions or among sub-areas of a region. A regional model is transformed into an interregional model by specifying not only sector origin but also regional location and destination of sector output.

It was argued above that because of the uncertainty of long-term forecasts for a large number of small sub-areas spatially disaggregated forecasts are not particularly useful. It can be argued, however, that the projections become more valid if there are larger and fewer zones considered. The uncertainty would decrease because larger zones mean the dynamics of the market would be more stable across zones. Also, stability would be greater if the projections were short-term, the products had high transportation costs, the products exhibited a major differentiation among sub-areas, and cultural and institutional factors such as loyalty, habit, inertia, and management policy were stable. While projections become more valid with larger zones, they are still best suited for short-term

analysis, unless simplying assumptions or extensive but questionable exogeneous analysis is made.[21] As Richardson has suggested:

> ...it may be simpler and no less accurate to use an I-O table for the region as a whole as the main forecasting tool, and then to employ ad hoc apportionment techniques...[22]

A short discussion of interregional I-O models is included because of the policy and impact applications at the provincial and regional level.[23] For example, the province's economic and land use impacts can be determined in any of the eight provincial regions. Or consider the impacts of shifts in industrial location and population, transportation planning, and spillover effects in sub-areas in terms of output, employment, income or fiscal resources. For regional planning, given the above limitations, a suitable interregional distinction would be between the centre city, the metropolitan area, the region, and the rest of the world.[24]

4.4.1 Isard "Pure" Interregional[25]

Isard argues that geographic flows are caused by: (1) geographically unbalanced distributions of population, income and resources; and (2) economies of scale. The former gives rise to heterogeneous market areas.[26] Since heterogeneous market areas are common, analytical techniques are required to take them into account. He proposes a general model which does recognize geographic inequalities and includes the heterogeneity of existing market areas. As a consequence, he argues, any commodity in a region must be unique from the same commodity produced in any other region. Isard's model has different technological matrixes for each region and for interrelations between regions. Thus, a commodity input from one region is assumed to be different than the same commodity input in another region.

The model's projections are only valid if the sub-areas exhibit constant relative supply prices and constant patterns of supply. As with all I-O input coefficients, the interregional input coefficients are assumed stable. Thus, an increase in demand will cause a proportionate and constant increase in the supply of inputs from all regions. Isard himself recognized the limitation this assumption places on projection applications. For projection purposes, one would have to expect stability in relative supply prices or do extensive side calculations; for example, using location theory, feasibility studies, marketing studies and ad hoc judgement. Another limitation is the extensive data requirements.[27] Since each table is built independently with an import row and export column for the rest of the world, the survey method is required. The model is best suited for impact analysis of how changes in one sub-region will impact on other sub-regions or on the region as a whole.

4.4.2 Leontief "Balanced" Interregional[28]

The balanced model is concerned with the relationships of goods among different sized market areas, say among the national, regional, and sub-regional markets. The classification of levels is arbitrary, here, and could theoretically include any number of levels in any size area. The model is based on the observation that some commodities are produced close to where they are consumed and others at farther distances. Thus, national commodities are easily transported and consumed in all areas in the nation, including large distances from the location of their production. In the model, the production and consumption of national commodities are balanced on the national scale. Regional commodities are consumed and produced in the region. They are balanced on the regional scale. The market level

disaggregation could continue to the n^{th} order sub-classification. The matrix of the model disaggregates commodities belonging to different levels of markets.

The model assumes each region's proportion of national level commodity output are constant. That is, regardless of the change in national output, the given percentage geographical distribution in output will remain the same. The structure of the model is, thus, represented by the normal input coefficients and regional-national output share coefficients. The latter represents the proportion of total national output of a 'national' commodity produced in a particular region. Given national final demands, the system can be solved for national outputs of any commodity in the regular format.

Outputs of regional goods are a little more difficult. First, the commodities are separated into regional and national classifications. Then, each regional commodity is disaggregated by region. The result is a set of regionally balanced equations (output minus intermediate demand equalling final demand) for each region. Each region's system can be described as an m x n matrix where m represents the number of regionally balanced outputs and n the number of commodities plus a final demand column. The number of commodities, n, includes both regional and national commodities produced in that region, because the total regional consumption of any regional commodity may also depend on non-regional inputs. Thus, the output of each regional commodity depends on the level of regional final demand and output demands of national commodities. The regional outputs of regional industries can be determined from regional final demand. The regional outputs of national commodities can be determined from the national outputs by the fixed share output coefficients. The

national outputs can be determined by a given set of national final demands. Thus, total regional output can be determined from sets of regional and national final demands.

The inputs are determined by two operations. The output of each industry located in the region is multiplied by the input coefficients of all their inputs. This summed, plus the total regional and national final demand for the region gives total regional consumption for a particular commodity.

Regional balances of trade are calculated as the difference between derived production and consumption for each commodity in each region.

The balanced model is generally developed from a non-survey approach. That is, a regional table will be dissaggregated into sub-regions. Alternatively, the pure interregional is built by aggregating a number of independent sub-regional tables. This, as the above illustrates, assumes the same input structure among sub-regions. The model is not, however, restricted to this assumption.[29] The model could adapt a pure interregional approach. Thus, a survey would be required. But generally, a non-survey approach is used, this being one of the positive features of the approach. The data requirements include a regional set of input-output coefficients, the regional outputs of regional industries, sub-regional distribution shares of regional industries and sub-regional final demands.

Another positive feature is ability to help analyze changes in interregional trade. The balance of trade output of the model, however, will not indicate the sub-regional location of imports or exports. Leontief assumes that the imports into any area will come from the nearest surplus area. However, the model is set up as a hierarchy of goods with market areas of different sizes and varying amounts of interregional

trade. As a descriptive planning tool it can be useful. As Leontief pointed out, if the table was triangularized, it could analyze:

> ...dependence and independence, hierarchy and circularity (or multi-regional interdependence)...the four basic concepts of structural analysis.[30]

With a given final demand, excess capacity, capacity constraints and possible import substitution can be identified. Thus, changes in a region's net trade balance can be forecasted, but not the locations of imports or exports.

The balanced approach also has a number of drawbacks. First, the constant national-regional proportionality assumption is limiting. Second, changes in regional final demand will not affect the output of any national industry. Thus, it is best suited for analyzing sub-regional implications of regional projections of regional industries when the location of the impact is not identified. Third, the industries classified into a category are not likely to have homogeneous markets. Fourth, each sub-regional industry is to some extent a regional industry. Fifth, there are regional differences in consumption and production. Sixth, by using the coefficients of a higher level region, the coefficients for the sub-region are less accurate. Finally, the model assumes there is no cross hauling. These drawbacks limit its accuracy for long-term forecasts. As a ad hoc apportionment tool, however, it can be quite useful.

4.4.3 Models Dealing with Interregional Trade

The models discussed below are, strictly speaking, not alternative to interregional models. Their purpose is to deal specifically with interregional trade flows.

The Chenery-Moses model is derived from base year interregional trade

flows.[31,32] It requires less data than the pure model but at the cost of two assumptions. One assumption is constant input trade patterns, that is, if a region imports a commodity from other regions in certain and fixed proportions, then all industries in the importing region imports that commodity from the same regions in the same proportions. The other assumption is a constant distribution of imports among consuming sectors in a region. Thus, imports are distributed in a region in the same manner they are produced in the region. The trade coefficient is calculated as a proportion of total sub-regional consumption; that is, sub-regional purchase of a commodity from a given sub-region as a fraction of total regional consumption. Forecasts of interregional trade are made by multiplying the base year coefficient by the forecasted regional consumption. This is, of course, based on the assumptions of constant import and constant distribution coefficients. If the coefficients can be estimated they could be replaced. In summary, the advantages are relatively less data requirements and locational specification of imports and exports. The disadvantages are the simplified assumptions.

Linear programing transportation type models offer another method of determining interregional trade flows. The data requirements include regional production and consumption of each commodity and average transportation costs per unit between regions. Regional trade is assumed to take place in a manner that will minimize transport costs. This approach is unsatisfactory because of: (1) data problems with getting actual transportation costs from surveys; (2) secondary data information on commodity transportation flows usually does not coincide with the sectoring scheme; (3) the model assumes no cross-hauls; and (4) the optimization technique underestimates the actual number of trade flows that actually occur.[33]

Various forms of gravity models can be used. The most notable one was developed by Leontief and Strout.[34] The model requires less data than a linear programing model because only relative distances not transportation costs are required. In the gravity adaptation, spatial commodity movement is related to production in the sending region, demand in the receiving region and distance between them. The model is not restricted to the constant coefficient assumption. However, the model does require base year data. The parameter estimates (a competitive factor, an isolation/ accessibility factor, a distance parameter to introduce non-linearity) are based on the base year data and assumed to apply to the future. The model is continuous. Also, the model cannot take into consideration changes in output and input requirements of sending and receiving regions. As a result, the output of the model is questionable. On the other hand, the data requirements are relatively minor.

In summary, the choice of whether to use and interregional model and, if so, between the interregional models and among the trade models depends on the purpose of the study and the time and resources alotted. The Chenery-Moses and pure interregional are advantageous when considering a single sub-region or its affects on other sub-regions. The balanced model, on the other hand, is advantageous in analyzing regional impacts on sub-regions.

4.5 Applications

I-O has many possible applications.[35] The problems it is intended to solve must be decided before the data is collected. Once the data is collected and compiled, certain problems cannot be analyzed because the structure of the model as designed would not allow it. The following is a

brief overview of possible applications. The aim is to demonstrate the usefulness of the I-O model in regional planning.

To the private sector, an I-O model can forecast sales by area, by number of establishments and by number of employees. Import substitution analysis will assist business development of new enterprises in the area. Aggregate growth projections and impact analysis will alert business to possible factor input shortages in the area. I-O is even more useful to the public sector.

To the public sector, the use in "consistent" forecasts of output, income and employment by sector and the input requirements was discussed in the last section. Another use is for fiscal impact analysis which could include the estimated tax base and services required. If considered prior to model development, the fiscal impacts of specific government policies or programs can be determined. The effects these changes will have on intergovernmental transfers can also be determined. In addition, in an interregional model the sub-regional fiscal implications of forecasted growth or specified impacts can be determined.

The highly disaggregated framework makes I-O very useful for analyzing impacts of private actions and public policies and programs on the economy as a whole and on individual sectors. Some specific problems that could be analyzed would include:

> ...water quality management, air pollution, sonic pollution, solid waste disposal, airport location, transport system redesign, land-use control, industry location, shopping centre location, crime and juvenile delinquency, housing and new town design, disarmament and conversion, social welfare program evaluation, open space, capital budgeting, unemployment and job opportunities, educational system reorganization, and slum clearance.[36]

Some of the above uses are included in what can be called *structural analysis* and *economic development*. This would also include

self-sufficiency analysis, per capita income and employment impacts of alternate developments, stability analysis, import substitution, bottlenecks, factor input shortages, and identifying the economic interdependence in a region. Also, by determining the full employment level of aggregate demand and by tracing back, one can find out which industries can contribute the most and how much they need to be stimulated. The above types of analysis can be done at a highly disaggregated industry level for the region and sub-areas within the region.[37] This type of analysis is especially important for it allows the local governments to determine the level and type of positive policies required for their economic development objectives. Positive policies could include: providing information and professional assistance; investment in training and education; discriminatory pricing practices for public utilities; direct financial aid including allowances, grants, loans and tax rebates; restricting development to selected growth points; and discriminatory allocation of services and infrastructure. I-O with the above analytical tools and the ability to forecast the impacts of fiscal government expenditures at all levels, gives the local governments a very useful tool in forecasting the overall magnitude, type, and location of growth within the region.

I-O is almost without competition when it comes to a model that can simultaneously analyze ecological, social, and economic issues.[38] Ecological, economic and social issues represent a complete set of regional planner concerns. While data is a major problem, I-O represents a framework which can work towards a one step social-environment-economic impact assessment.

In analyzing alternate policies and programs, it can be argued that both efficiency and equity impacts should be considered.[39] The I-O framework is ideally suited to this because household income could be disaggregated by socio-economic classes and sub-regions. The effect policies and programs will have on different income groups could be evaluated. Analysis along this line could be extended to developing a Bergsonian *social welfare function*. The function includes both equity and efficiency considerations. The function could be specified by some political-administrative means, then maximized using the I-O table and linear programming. Industry development would then be encouraged or restricted according to their efficiency and equity contributions to the region.

4.6 Summary

The input-output framework is recommended as the most suitable forecasting tool. Its primary advantage is its highly flexible, disaggregated and comprehensive structure. This allows the analyst to examine more clearly the economic interrelations within and among regions. Also, the analyst is capable of introducing structural changes into the forecasts. In addition, I-O is capable of a large number of policy and impact applications. The I-O technique, therefore, is recommended because: (1) its suitability to the needs of the regional plan, such as long-term forecasts; (2) the relative accuracy of the forecasts; (3) the uses for policy and impact analysis for the Regional Plan and the uses in other areas. Our special concern here, as illustrated in the next chapter, is the uses of I-O and linear programming used together. In the next chapter, the focus is back towards forecasting land uses.

Footnotes

[1]This discussion follows the presentation in Werner Z. Hirsh, *Urban Economics Analysis* (New York: McGraw-Hill, 1973), pp. 173-268.

[2]Ibid.

[3]B.M. Rubin and R.A. Erickson, "Specification and Performance Improvements in Regional Econometric Forecasting Models: A Model for the Milwaukee Metropolitan Area," *Journal of Regional Science,* 20 (February 1980), pp. 11-35.

[4]To my knowledge there are no comparative studies on the accuracy of I-O and export-base forecasts. Accuracy tests with comparative models will depend on the nature of the tests and the nature of the actual models built. In at least two tests I-O did compare favourably with Keynsian frameworks. See Leontief, *The Structure of the American Economy;* Harold Barnett, "Specific I-O Projections," *Long-Range Economic Projections: Studies in Income and Wealth,* (Princeton: Princeton University Press, 1954); Hollis B. Chenery and Paul G. Clark, *Interindustry Economics,* (New York: John Wiley & Sons, 1959), pp. 173-76; and Robert B. Williamson, "Simple Input-Output Models for Area Economic Analysis," *Land Economics,* 46 (August 1970), pp. 333-38.

[5]Criticisms of export-base can be found in Hirsh, *Urban Economic Analysis,* pp. 192-94; Walter Isard, et.al., *Methods of Regional Analysis: An Introduction to Regional Science,* (New York: MIT Press, 1960); R.W. Pfouts, "An Empirical Testing of the Economic Base Theory," *Journal of the American Institute of Planners,* 23 (1957), pp. 64-69; and R.W. Pfouts, *The Techniques of Urban Economic Analysis,* (New Jersey: Chandler-Davis Pub. Co., 1960), passim.

[6]Meirnyk states, "while a regional I-O table based on 'adjusted' national coefficients can give a rough description of a regional economy, it is virtually useless for projection purposes." He argues that adjustment techniques do not allow for differences in industry and product mixes among regions. Even if they could be adjusted, it still cannot be used for long-run consistent forecasts because it does not provide information about changes in the direct coefficients over time. Differences in national and regional aggregation schemes creates a problem. In addition, secondary employment data is most often used in the adjustment techniques. It is unlikely that the employment data will be published in the same categories as desired by the sector definition. See W. Meirnyk, "Long Range Forecasting with a Regional Input-Output Mode," *Western Economic Journal,* 6 (June 1968), pp. 165-76.

[7]A complexing problem is that it takes a long time for the multiplier to work itself through.

[8]This analysis is taken from Hirsch, *Urban Economic Analysis,* pp. 194-210; William H. Miernyk, *The Elements of Input-Output Analysis* (New York: Random House, 1957); Harry W. Richardson, *Input-Output and Regional Economics* (London: Weidenfeld and Nicolson, 1972); Walter Isard and Thomas W. Langford, *Regional Input-Output Study: Recollections, Reflections and Diverse Notes on the Philadelphia Experience* (Cambridge, Massachusetts and London, England: MIT Press, 1971); R.C. Jensen, et.al., *Regional Economic Planning: Generation of Regional Input-Output Analysis,* (London: Groom Helm, 1979); and P. Smith and W.I. Morrison, *Simulating the Urban Economy: Experiments with Input-Output Techniques* (London: Pion, 1974).

[9]For a discussion see Jean H.P. Paelinck and Peter Nijkamp, *Operational Theory and Method in Regional Economics* (Westmead, England: Saxon House, n.d.), pp. 262-328; Isard, *Methods of Regional Analysis,* Chapters 9 & 12; Wassily Leontief, "Multi-regional Input-Output Analysis," in T. Barna, *Structural Interdependence and Economic Development* (London: McMillan & Co. Ltd., 1963), pp. 105-18; W. Isard and R.E. Kuenne, "The Impact of Steel Upon the Greater New York-Philadelphia Urban Industrial Region," *Review of Economics and Statistics,* 35 (November 1953), pp. 289-301.

[10]See footnote 8 above for the references to this section.

[11]The theoretical development of this procedure is accredited to Wassily W. Leontief who published his ideas first in "Quantitative Input-Output Relations in the Economic System of the United States," *Review of Economics and Statistics,* 18 (August 1936), pp. 105-25. Later with an application he published *The Structure of Amercian Economy, 1919-1939: An Empirical Application of Equilibrium Analysis,* 2nd ed., (New York: Oxford University Press, 1951).

[12]Richarson, *Input-Output,* p. 8.

[13]With the exception of exports, the table can be closed with respect to the other exogeneous sectors. See W. Lee Hansen and Charles Tiebaut, "An Intersectoral Flows Analysis of the California Economy," *Review of Economics and Statistics,* 45 (November 1963), pp. 409-18.

[14]Developed by F.T. Moore and J.W. Petersen, "Regional Analysis: An Interindustry Model of Utah," *Review of Economics and Statistics,* 37 (1955), pp. 363-83.

[15]This discussion follows that found in Richardson, *Input-Output,* Ch.9.

[16]Linear programming was developed by G.B. Dantyig, "Maximization of a Linear Function of Variables Subject to Linear Inequalities," in T.C. Koopmans (ed.), *Activity Analysis of Production and Allocation* (New York: John Wiley & Sons, 1951), pp. 339-347.

[17]This discussion follows that found in Robert Dorfman, Paul A. Samuelson, and Robert M. Solow, *Linear Programming and Economic Analysis,* (New York: McGraw-Hill, 1958), passim.

[18]Ibid., p.8.

[19]This point is significant to the model recommended below.

[20]S. Chakravarty, "The Use of Shadow Prices in Program Evaluation," in P.N. Rosenstein-Rodan, ed., *Capital Formation and Economic Development,* (Cambridge, Mass.: MIT Press, 1964), pp. 49-50.

[21]Alterations to the basic models would have to consider localization economies, agglomeration economies, urbanization economies, changes in relative supply prices causing substitution, changes in transportation costs, technological changes in introducing new products, import substitution, and.resource constraints not entering the analysis directly.

[22]Richardson, *Input-Output,* p. 249.

[23]The level at which interregional models can be built is somewhat arbitrary. That is, it can be built as a system of eight regional models at the provincial level or as a number of sub-regional models at the regional level.

[24]The usefulness to planners of the centre city, suburban area, and rest of the world distinction was highlighted by Abe Gottlieb, "Planning Elements of an Interindustry Analysis: A Metropolitan Area Approach," *Journal of the American Institute of Planners,* 22 (1956), pp. 230-6.

[25]Walter Isard, "Interregional and Regional Input-Output Analysis: A Model of a Space Economy," *The Review of Economies and Statistics,* 33 (November 1951), pp. 318-28.

[26]Heterogeneous market areas mean that two producers, each in a different area, will have different size markets because of their proximity to their inputs and buyers.

[27]However, after his experiences with building the Philadelphia input-output model, Isard acknowledges the feasibility of building a pure interregional model. See Isard and Langford, *Regional Input-Output Study*, p. 16.

[28]Wassily Leontief, "Interregional Theory" in Leontief, *Studies in the Structure of the American Economy*, pp. 93-115.

[29]Ibid., p. 100.

[30]W. Leontief, "The Structure of Development," *Scientific America*, 209 (September 1963), pp. 148-66.

[31]H.B. Chenery, "Interindustry Analysis of Development Programing," in T. Barna, ed., *Structural Interdependence and Economic Development*, (New York: John Wiley & Sons, Inc., 1956).

[32]L.W. Moses, "A General Equilibrium Model of Production, Interregional Trade and Location of Industry," *The Review of Economics and Statistics*, 42 (1960), pp. 373-97.

[33]This is intuitive as one would not expect trade flows to be as efficient as the optimal behaviour.

[34]Wassily Leontief and Alan Strout, "Multi-regional Input-Output Analysis," in T. Barna, ed., *Structural Interdependence and Economic Development*, (London: MacMillan & Co. Ltd., 1963), Chap. 7.

[35]This discussion is taken from Miernyk, *Elements of Input-Output Analysis;* Werner Z. Hirsch, "Application of Input-Output Techniques to Urban Areas" in T. Barna, et.al., *Structural Interdependence and Economic Development* (London: MacMillan & Co. Ltd., 1963); W.I. Morrison, "Input-Output Analysis and Urban Development Planning: Some Applications of the Peterborough Model" in W.I. Grossling, ed., *Input-Output and Throughput*, (London: Input-Output Publishing Co., 1971); Werner Z. Hirsch, "Input-Output Techniques for Urban Government Decisions," *American Economic Review*, 58 (May 1968), pp. 162-70; Abe Gottlieb, "Planning Elements of an Interindustry Analysis - A Metropolitan Area Approach," *Journal of American Institute of Planners*, 22 (1956), pp. 230-36; Isard and Langford, *Regional Input-Output Study*.

[36] Isard and Langford, *Regional Input-Output Study*.

[37] Ibid., p. 22.

[38] A recent example of I-O used in analyzing alternate economic development impacts is published in Gerald R. Barnard and Warren T. Dent, "Policy Simulations of Alternative Futures," *Regional Science Perspectives*, Vol. 9, no. 2 (1979) pp. 1-30. The impacts included: changing the industrial mix to emphasize manufacturing; increasing processing and packaging of agriculture products; promotion of human resources development; transportation improvements including a freeway system and branch line maintenance; developing coal under environmental quality standards; implementation of a land use policy which restricts confinement feeding of cattle and; promotion of industrial development through readily available supplies of energy. Also, see Walter Isard, et.al., *The Ecological-Economic Analysis for Regional Development* (New York: The Free Press, 1972); and W.Z. Hirsch, S. Sonenblum and J. St. Dennis, "Application of Input-Output Techniques to Quality of Life Indications, *Kyklos*, 24 (1971), pp. 511-32.

[39] See Morrison, "Input-Output Analysis and Urban Development Planning".

CHAPTER V

INPUT-OUTPUT AND LINEAR PROGRAMMING APPLICATIONS TO LAND USE

The analysis of models started in Chapter III with the review of land use models. That chapter concluded that a macroeconomic model as opposed to a land use model would be more suitable. In Chapter IV, the different macroeconomic models were reviewed; I-O was recommended as the most suitable. This chapter presents the focus of the thesis; the land use plan design model. An I-O model can be adapted for a land use plan design model in two ways. First, as a purely "positive" approach, the planner can convert the I-O data to determine land requirements. Section 5.1 reviews two approaches of doing this. A second approach (or rather an extension) gives the process a "normative" context. This second approach is achieved with the inclusion of linear programming optimization techniques. Section 5.2 reviews two land use plan design models which used linear programming. Section 5.3 develops a new approach to using I-O and linear programming to analyze land use in a region. This last section represents the main theoretical contribution of this thesis.

5.1 I-O Land Use Adaptions

The literature illustrates two techniques which can be called *flows of rental space* and *land input rows*.

5.1.1 Flows of Rental Space[1]

This procedure involves building a transaction table with square meter flows of inputs to outputs. The table could be constructed in the following way. A survey is taken to determine the average rent per square meter for each sector. This divided into each value of the regular transactions table times the total square metres per sector would turn it into a flows of square meters of space transactions table.[2] This technique can yield per sector values of the direct amount of floor space used, direct space used per million dollars worth of output, and direct plus indirect (and induced) space used per million dollars worth of output delivered to final demand. The validity of this method depends on the following *factorability* assumption:

> All the outputs from any given sector should have identically the same relative composition of inputs, regardless of which the receiving sectors are, and regardless, also, of the length of the chain of sectors that only indirectly, via other sectors, receive the outputs in question.[3]

To be used for projection purposes, estimates of changes in the productivity of land use and changes in the rent per square meter by sector have to be made. The model could include residential land use if the model was "closed" with respect to households. Also, one can see the interesting results if this was built in an interregional model. The result would be a table of land uses displaying the hierarchial and circular spatial interdependence in the region.

5.1.2 Land Input Rows[4]

This technique involves the inclusion of hectar or square meter row(s) in the transaction matrix. The transactions matrix could include a number of rows for alternate land uses. Two schemes are: high density commercial, medium density commercial, etc., and/or floor space, parking,

and land reserve. The transactions matrix would include corresponding zero columns to justify the inclusion of stocks and flows in the same matrix. The technical coefficient matrix is made by dividing each column entry by the output level of that column adjusted by inventory changes. The entries in the land rows express hectare or square meters per dollar of output. The direct, indirect and induced impacts for increases in final demand can also be calculated. The computational problems are similar to the flows of rental space method. In particular, one would not expect production functions to be linear and homogeneous with respect to land. This method does allow greater disaggregation by type of land use. On the other hand, the flows of rental space method indicates the type and extent of industry interdependence with respect to land. Both models have different applications and are complementary because they do not require any additional data. They are also complementary to a third, obvious method; applying acreage or square meter/output ratios to the projected output of each industry.

These approaches are strictly "positive". They give no indication of what amount of land allocation would be Pareto optimal. "Normative" approaches are considered next.

5.2 Linear Programming Land Use Planning Applications

At any level development plan, the planner's problem is one of choosing the optimal land uses within the geographical confines of the plan. The planner must determine the types of land uses, the amount of each type and the location within the area. In addition, when it will be absorbed is also an important question. As discussed above, projection models are more applicable to higher level plans. Also, the iterative

nature of the planning process is an efficient and flexible means of bringing raw land to fully serviced and zoned. Because the higher level plans leave flexibility for lower level plans, lower level plans can accurately reflect the market demands at that time. A higher plan level forecasting model which determined definitive land uses for lower level plans would be too rigid. Also, the definitive results of the long-term forecasts would be questionable. Thus, to some extent the when and where questions are better dealt with by the planning "process" than planned a long time in advance with a planning model. Therefore, the concern here is for approaches that answer the "type" and "how much" questions.

This section is primarily concerned with plan design models; as distinct from economic planning models. This is not to imply that an economic planning model should not be used prior to the plan design stage. At the provincial level, optimal economic activity for each region could be determined. This data would then be used as input into each regional plan design. In fact, I-O is well suited for this purpose. The discussion below, however, concentrates on the purpose of this thesis; that is, a land use plan design model.

The planning framework is one of developing plans which will maximize some goal(s) or objective(s). A linear programming adaptation gives I-O goal or objective achieving capabilities. From a policy point of view, I-O is neutral. Linear programming can allow any kind of policy analysis. It can include both efficiency and equity considerations. In addition, it can be argued that planning goals are not quantifiable. On the other hand, any plan is designed in quantifiable terms from an attempt to achieve those goals. With linear programming, goals can be evaluated directly by

entering goals in the objective function, or in a sensitivity analysis by entering goals as constraints. The goals can range, for example, from maximizing income to minimizing the cost of servicing to maximizing the number of residential units in the plan area.[5] In any formulation, the planner is trying to choose a plan design which will maximize the well being of the area as defined by the objective function. Because of the size of the area, and nature of the plan, less fundamental welfare functions (goal or objective function specifications) are not considered below; for example, maximizing the number of residential units. On the otherhand, the goals must be broad but not so abstract as to limit a quantification.[6]

The objective function must not be so complex that policy-makers do not know what they are trying to optimize. In the same respect, policy-makers must not lose sight of which constraints are affecting what activities in the objective function. As discussed below, the constraints can reflect the policy-makers policy options as well as scarce resources. Finally, as discussed above with relation to land use models, the linear programming formulation should not be so complex or expensive as to prohibit its applicability.

There can be many alternate linear programming formulations of the plan design problem. The formulations discussed below are representatives of the major alternatives and fall within the guidelines mentioned above.

5.2.1 Cost Minimization

Schlager presented the seminal land use plan design model.[7] The structure of his model is one of the many possible adaptations of the standard linear programming cost minimization approaches. He describes the

land use plan design problem as: given the design requirements (expressed as design standards for each land use) and a set of demands for each land use, synthesize a land use plan that satisfies both the design standards at a minimal combination of public and private cost. This last proviso becomes the objective function. That is, the objective is to minimize the public and private cost of developing the total amount of land in the plan area. Schlager's application used costs of raw land plus development costs for total costs of each land use type. These costs per acre are parameters of the objective function.

The objective function is constrained, first, by the total demand for each land use category. Total demand is determined exogenously. The coefficients for this constraint are service ratios; percentage of land for streets, parks, etc. for each land use. The second set of constraints puts minimal limits on each land use within each zone. The final set of constraints attempt to solve the land use mix problem by limiting the amount of one use in a zone relative to another use. The last two sets of constraints are determined by design standards.

This type of an objective function would be suitable for lower level plans; such as neighbourhood or outline plans. In higher level plans, a broader definition of the social goal(s) in the plan is required. The optimal amount of land in the sub-area and land use mix problems solved by the second and third set of constraints, respectively, are not relevant to the problem at hand; as discussed above. The first set of constraints, however, is quite relevant to the problem at hand. First, one could argue that since the only policy the planner has within his control is amounts of land use they should enter as constraints. In this way he can perform sensitivity analysis on the effects of his policies. Also, the shadow

prices in the dual will give the value of land in each alternate use. This is an important characteristic as is demonstrated below.

5.2.2 Profit Maximization

Boaden's work is another land use plan design model using linear programming.[8] It is a variant of the standard linear programming profit maximization approach. His model incorporates both linear programming and discounted cash flow concepts. The objective function is a profit function which has a variable and a fixed component. The variable component is net present value of variable cash flows per unit of each land use times the number of units of the respective land uses. The fixed component is the net present value of fixed cash flows. The fixed discounted cash flow and the variable discounted cash flows are inputs into the linear programming model. An application of his general formulation was not given. The first set of constraints include land, labour and capital. The second set of constraints, the author suggests, can include anything with which the planner wishes to constrain the objective function; density constraints for example. The author emphasizes the analytical value of the model is its ability to test the sensitivity to constraints. The importance is that the constraints can represent goals. As discussed with regard to the cost minimization method, this is an important device for a planning tool to have.

This profit approach is also more suited for lower level plans. the discounted cash flow for different land uses in the time length and of the scale required by the Regional Plan would be difficult to obtain in any degree of accuracy. Also, the profit goal is too narrow. It does not

include all the groups in society affected by the land allocation. He did not present an application, thus, an explicit representation of the constraints was not made. The first set of constraints (land, capital, labour) are simply worth noting. The second set of constraints, basically the idea of including policy options as constraints, is also worth noting.

These two approaches can be complementary in the classical primal-dual relationship of linear programming. This depends, however, on how one defines the costs, the profits and the constraints. For example, the shadow prices for the constraints in the costs minimization case are difficult to interpret in the profit maximization case. One could interpret the first constraints' shadow prices as the marginal addition to profit from having an optimal amount of each land use given the costs of services associated with each use. The second one can be interpreted as the marginal change to profit from having an optimal mix of uses among zones. The final set of constraints can be interpreted as representing the marginal change to profit from the optimal relative mixes of land use within a zone. One could assume that these considerations were taken into account in the net present value calculations of the profit maximization example. This is simply an interpretation. The point is that a primal-dual reconciliation depends on what the analyst defines costs, profits and constraints; and whether these are directly comparable. A second point is the objective function and constraints can contain social goals and objectives. Given different social environments, therefore, there can be many different formulations of either cost minimization or profit maximization; also depending on the level of the plan and the nature of the planning problem.

These approaches were reviewed to introduce linear programming applied to the plan design problem. Also, their disadvantages and advantages to the design problem approached in this thesis were worthy of noting. The nature of these problems are different, therefore, no further comparison is made between the above models and the one developed below.

5.3 A New Approach

The following approach is a variant of the classical profit maximization linear programming framework. It incorporates some of the ideas presented in the cost minimization and profit maximization above and includes some new ones.

It can be argued that the regional objective function to be maximized should represent aggregate regional income. First, the scope of the plan is broad, affecting most groups and institutions in the region. Plan alternatives, therefore, should be evaluated as to their affects on a fundamental index as income. Second, with income, policy-makers have a clear concept of what they are trying to maximize in plan alternatives. Third, with the I-O information, it is feasible in terms of data availability. Finally, as will be shown below, it allows one to easily evaluate efficiency and equity considerations.[9]

The constraints, it is argued here, should include limits on specific land uses and limits on aggregate output growth. The primary responsibility of planners for the Regional Plan is to determine the land use allocation. As described above, the planner achieves this by considering the design requirements (existing policies affecting land use) and the demands for different types of land. This problem would be trivial

if there was an infinite amount of land, but there is not. Land is a scarce resource. The planner must determine which land uses take preference over the others. In the Regional Plan, this was done in an ad hoc basis using pre-defined priorities. These priorities were not determined on the basis of actual value of the land. Including land uses as constraints in the primal problem gives, in the dual, shadow prices associated with each land use. Given income in the objective function, it can be argued that the shadow prices include both private and social preferences for each land use. The planner may alter the individual land use constraints and observe the effects on prices in a sensitivity analysis. The object of the sensitivity analysis, therefore, may be to allocate land based on the demand elasticities.[10] The planner acts as a monopolist, allocating less than the Pareto optimal amount to land uses with inelastic demand and more to uses with an elastic demand. This assumes that the planner's objective is to maximize the total land values of the region. Also, constraints on aggregate output growth are required to ensure any capital and labour limitations are not exceeded.

The model described is of the following form:

$$\text{Maximum} \quad \tilde{\Pi} = CX$$

Subject To:

$$\begin{aligned} 1X &\leq L \\ [I-A]\,X &\leq F \\ X &\geq 0 \end{aligned}$$

Where

C = a vector of value added coefficients defined as the total value added as a ratio of the value of output for each sector at time t

X = a vector of outputs at time t, where t is the year for which forecasts are required

l = a matrix of land input coefficients defined as the hectares or hectare-square metre required per million dollars of output for each sector during time t[11]

L = a vector of aggregate amounts of each type of land use available during time period t

[I-A] = the Leontief matrix

F = a vector of predetermined final demands at time t

The corresponding "dual" is as follows:

$$\text{Minimum} \quad \widetilde{\Pi}^{*} \geq [L' : F']\,Y$$

Subject To:

$$[l' : I-A']\,Y \geq C$$
$$Y \geq 0$$

Where

Y = a vector of shadow prices for land inputs and activities associated with final demand.

The above model is an income optimization model with one primary scarce resource, land. There is a set of land constraints because land can vary in quality and, thus, productivity. Other scarce resources can be imputed in the final demand constraint. The land input coefficients represent flows of land. They also represent stocks. Because land can be considered as a stock and a flow, this allows one to utilize the mathematics of linear programming and the practical application. For the practical application, the constraints represent aggregate land requirements associated with a given volume of output produced during time t. This will be elaborated on below. Their values and the land input coefficients can be obtained along with the survey data for the I-O table. The land input coefficients can be calculated as follows. First, the total rent of each land use type for each sector is obtained. The time period the rent covers has to coincide with the time period the rest of the

input-output values cover; typically one year. Second, the rental value is mapped to the associated amount of space that rental value could purchase. Then, those rental space amounts are divided by the associated sectors output. Any reference to land input coefficients that follows is to be given this interpretation.

Let the above model represent the base case from which to discuss the planner's problem. The first thing to notice is the assumption that land is the only scarce factor. For this to be true then in the optimal solution, the effective demand must be greater than the level of output by at least as many activities as there are land uses. That is, all the land use constraints are binding.[12] This begs the question of how the values of the constraints were determined in the first place. The final demand constraints could be determined as follows. A range of sectoral final demands are determined based on alternate assumptions of the future state of the world. This most probable set of final demands are translated into sectoral industrial output required up to that time period. The required capital and labour are estimated. This demand for labour and capital are compared to exogeneous estimates of labour and capital supply. A sectors final demand is adjusted back for any supply limitations. The land constraints, Ls, can be calculated in relation to the effective output estimates.[13] That is, projected output for each sector is multiplied by the respective land/output coefficients. Because X, L, l, and F are calculated at a certain projected time period, they are consistent with each other. Thus, L and F are calculated to be just binding. At this stage, the planner has two options. In the first option, in calculating the Ls, he does not adjust output, Xs, according to the new set final

demands; which were constrained by capital and labour shortages. In this case, certain final demand categories can constrain output before certain land constraints bind. The respective Ls, which are not constraining, would not have a positive shadow price. The planner could use the effective demand of the unconstrained Ls and the constrained Ls to determine the land allocation. In the second option, the planner would adjust output, Xs, when calculating Ls to include labour and capital constraints on final demand. In this case, land, Ls, would reflect the same capacity constraints as final demand, Fs. Therefore, final demand constraints would be trivial and could be excluded. Each land use, Li, would have a positive shadow price. In practice, either option would prove useful. Both could be done with little additional work.

The final consideration is to alter the amounts of land use, Ls, required to be consistent with the total amount of land available in the region. It is irrelevant whether they were originally valued at hectares or hectare-square meters. In either case, the density assumptions would be adjusted until total regional land demanded equals that available. The planner would make the adjustments in an ad hoc manner according to each land use's suitability of changed density and its shadow price.

These concerns of adjusting each land use category and consistency with total available land can be resolved, in part, in a more elegant and efficient solution procedure; presented below.

This case can be described as follows:

$$\begin{aligned} \text{Maximum} \quad & \pi = CX \\ \text{Subject To:} \quad & 1X - L = 0 \\ & \sum_{i=1}^{N} L_i = Lo \\ & [I-A]\, X \leq F \\ & \geq 0 \end{aligned}$$

Where

Lo = the total amount of available land in the region in time period t.

In this case, the solution gives optimal values for output (Xs) and amounts of land use (Ls) which maximize regional income.[14] A drawback of this case is rigid density restrictions; where, in fact, land can constrain output. This statement requires some explanation. Generally speaking, the planner's objective is not to restrict growth. Rather they must allocate this growth to alternate land uses in a way which maximizes the growth in the Region. Again, however, the planner can achieve a more optimal solution by heuristic methods. He can change the $\Sigma Li = Lo$ constraint to an $\Sigma L < Lo$ constraint. Then Lo is increased or decreased to where it is just binding, say Lo*. The densities are adjusted proportionately to bring equivalence between Lo* and Lo. The other drawback is possibility of negative shadow prices because of the equality sign.[15] However, this possibility is very slight given the broad categories. In more precisely zoned categories, this is a very real possibility; in fact, negative externalities is the major reason for zoning.

In the above examples, the planner was concerned with maximizing regional income and also maximizing land values. Are these compatible? What should be the planner's true objectives? It was argued above that region income was the appropriate social welfare measure to optimize. Besides being broad, etc. as discussed above, the planner can include efficiency and equity considerations. This is done by altering preferences in the social welfare function. The preferences are represented by the value added coefficients. By breaking down these coefficients one can

determine, for example, the relative labour, profit and import shares of this sector. Also, from an environmental prospective, environmental impacts from each sector can be determined. Another interesting application is the use of urban income, as obtained from the I-O model, as an indicator of wealth for taxation purposes. With this information a political-administrative body can fix the preference weights different from those determined by the I-O data. This would represent a more local social welfare function as the I-O data represents economic relationships largely influenced by exterior factors. Therefore, the planner's true objective should be maximizing regional income. But what of the maximizing land value objective?

If land values accurately reflect social values, then the planner should strive to maximize land values.[16] It is assumed, or rather, proposed that higher aggregate land values lead to a more efficient utilization of the resource land.[17] There is no argument with this as an objective but rather in how it is achieved. If the planner achieves this through a well planned town then the statement has merit. If, however, he achieves maximum land values by acting as a monopolist then it does not. The monopolist behaviour of the planner is an imperfection, hindering the efficiency of the land market. Thus, the maximizing land value objective has merit if achieved by improving the efficiency of the resource use. The two objectives, therefore, are compatible if the land valuations are social valuations (which they are in this case) and the most efficient use of the resource is achieved.

Another more general rule has been suggested by McMillan.[19] The rule is based on the fundamental definition of economic efficiency. Efficiency requires that the marginal value per unit cost of each input in production

be equal.[20] Therefore, for an optimal distribution, homogeneous land should be allocated to alternate uses until the marginal values in competing uses are equal. Since we are not considering the locational assignment, that is, the "where" question, all uses are competing uses in the Region. To apply this rule to the problem at hand, we turn to the shadow prices. The meaning of the shadow prices are simply marginal value products.[21] If the primal contains land constraints then the dual gives marginal value products for each land use. Note, the planner is free to vary the land constraints ex-ante. Therefore, the optimal solution is one where the shadow prices are constrained to be equal to each other and the land use amounts altered accordingly.[22] The procedure is illustrated in the following example.

Consider the regional land which the growth will be allocated as homogeneous land. Assume that there are only two types of land uses; agriculture and urban. This land is assumed to be the only scarce factor in the production of goods X_1 and X_2. Note, part or all of any of these goods may require agriculture land. In this example, urban and agriculture product production are restricted to their respective land use classes; thus, substitution is not permitted. This was done to simplify the illustration, but certainly is not the case in general. In general, for example, certain types of commercial industries could locate in high density commercial, low density commercial, industrial, or residential land. The problem is formulated as follows:

PRIMAL

$$\text{Maximum} \quad \pi = .2\,X_1 + .1\,X_2$$

$$\text{Subject To:} \quad \begin{aligned} X_1 \qquad &\leq 1 \\ X_2 &\leq 1 \\ X_1, \quad X_2 &\geq 0 \end{aligned}$$

FIGURE 4a: PRIMAL

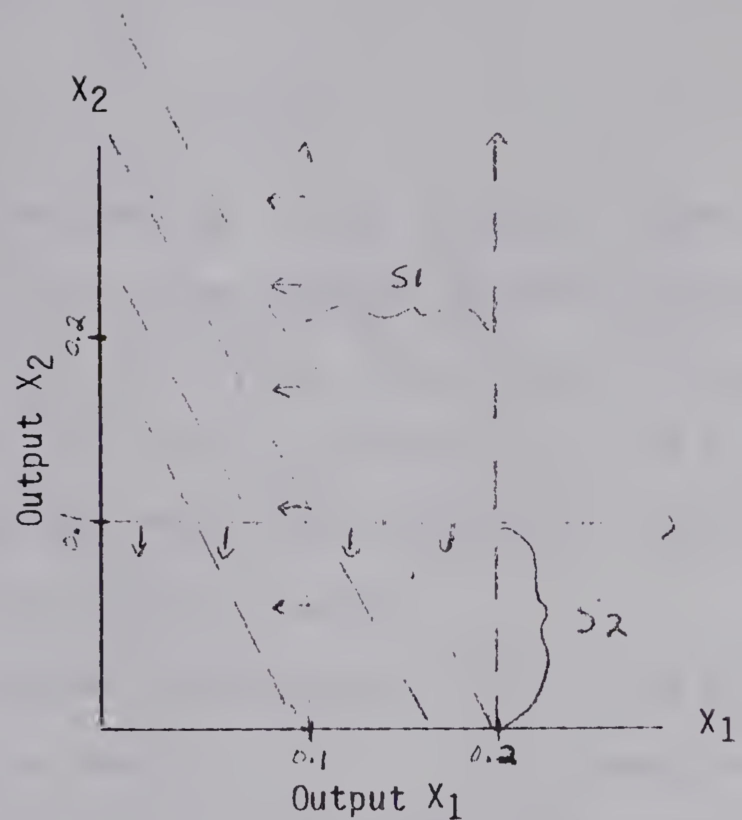
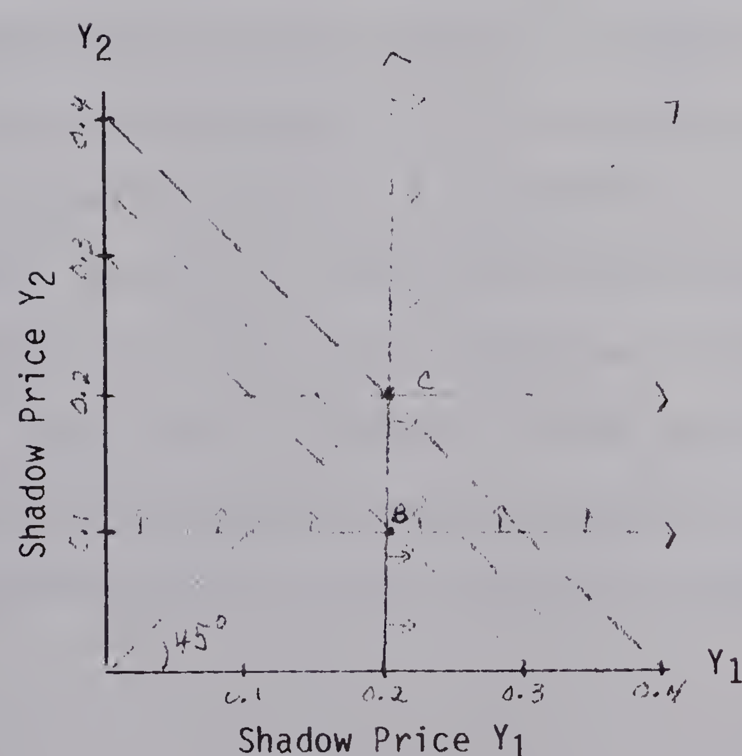


FIGURE 4b: DUAL



DUAL

$$\text{Minimum} \quad \widetilde{\Pi}^{\circ} = Y_1 + Y_2$$

$$\text{Subject To:} \quad \begin{array}{l} Y_1 \qquad > 2 \\ \qquad Y_2 > 1 \\ Y_1, \; Y_2 > 0 \end{array}$$

The primal's objective function is total regional income. The value added coefficients (.2, .1) are value added per trillion dollars of output. The primal's constraints are one million acres of urban land and one million acres of agriculture land. The dual variables, Y_1 and Y_2, are shadow prices for urban and agriculture land respectively. The solution can be shown graphically, see figures 4a and 4b.

The optimal solution to the primal is $X_1* = 1$ and $X_2* = 1$ and the value of the objective function $\widetilde{\Pi}* = .3$. This means the first and second industry produce 1 trillion dollars of output each and the total region income is .3 trillion dollars. The optimal dual solution is $Y_1* = .2$ and $Y_1* = .1$ and $\widetilde{\Pi}^{\circ}* = .3$. The shadow prices or the per unit imputed value for use in production for urban and agriculture land are .2 trillion and .1 trillion dollars respectively; refer to point b in figure 4b. The value of the dual objective function represents the total imputed value or opportunity cost of resources available for production. If the constraints are fixed and given by the actual resource limitations then this is the most efficient distribution of land into production. The planner has the option, however, to change the distribution of land, ex-ante. Since urban yields .2 trillion dollars per million acres and agriculture only .1, then clearly, from an efficiency point of view, we would be better off to put

This revised allocation can be achieved by setting the shadow prices equal: that is, $Y_1 = Y_2$. This is represented by the 45° line in the dual graph (figure 4b). With this constraint, the optimal value of the shadow prices are both two and the objective function $\pi^{0**} = .4$; at point C. Since in the optimum $\hat{\pi} = \hat{\pi}^0$ the optimum value of the primal objective function is four also. Given the primal problem defined above this does not seem possible. However, with the $Y_1 = Y_2$ constraint in the dual, the primal problem is no longer the same. This constraint forces the primal problem to loosen (or tighten) its constraints by introducing slack (or surplus) variables. The vertical constraint moves to the right to account for the surplus of X_1 created (S_1) and the horizontal constraint moves down to reflect the slack of X_2 (S_2). The new optimal solution works out to $X_1^{**} = 2$ and $X_2^{**} = 0$. In the "efficient" solution, therefore, urban uses (X_1) received more land because its value to output was greater.

This approach can be generalized as follows:[23]

PRIMAL

Maximum $\hat{\pi} = V X$

Subject To:

$$\left[\begin{array}{c|c} 1 & \\ \hline I-A & D \end{array}\right] \left[\begin{array}{c} X \end{array}\right] < \left[\begin{array}{c} L \\ \hline F \end{array}\right]$$

DUAL

Minimum $\hat{\pi} = [L':F']\ Y$

Subject To:

$$\left[\begin{array}{c|c} 1' & (I-A)' \\ \hline \multicolumn{2}{c}{D'} \end{array}\right] \left[\begin{array}{c} Y \end{array}\right] \geq \left[\begin{array}{c} V' \end{array}\right]$$

Where

V = $1 \times N + r - 1$ vector of N value added coefficients defined as value added per million dollars of output and $r - 1$ coefficients of value 0 associated with the slack variables

X = $N + r - 1$ vector of N sectoral output variables and $r - 1$ unconstrained slack variables at time t, where t is the year which forecasts are required

l = $r \times N$ sub-matrix of land input coefficients defined as hectares per million dollars of output during time t

I-A = $N \times N$ Leontief input-output matrix (direct coefficient matrix)

L = $r \times 1$ sub-vector of amounts of different types of land use during time t

F = $N \times 1$ sub-vector of effective final demands

Y = $r + N \times 1$ vector of shadow prices for land and final demand respectively during time t

D' = $r - 1 \times r + N$ matrix binds the shadow prices to equivalent values and is of the following values:

$$\begin{bmatrix} 1 & -1 & 0 & 0 & \cdots & \cdots & 0 \\ 1 & 0 & -1 & 0 & \cdots & \cdots & 0 \\ 1 & 0 & 0 & -1 & \cdots & \cdots & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdots & \cdots & 0 \\ 1 & 0 & 0 & 0 & \cdots & -1 \cdots & 0 \end{bmatrix}$$

The D' matrix forces all the shadow prices to be equal. This in turn gives values to the slack variables in the X vector. The slack variables are, of course, measured in the same terms as L. The optimal solution for amounts amounts of each land use is obtained by subtracting the slack variables

from the L sub-vector. The result is land allocated to uses based on the marginal value product for each use.

The key feature of this last approach is the technique for "efficient" allocation of land. It is preferable to the other two linear programming approaches because it applies the economic efficiency rule to allocating land among competing uses. This is not to say that all three approaches can not be used in practice. Each may provide different types of information. Also, the other two would take little additional work to set up once one is done.

In practice, planners could utilize the approaches developed here in the following way. First, the values for V, X, l, I-A, L, and F would be determined as projections at time period t. These projections would result from an economic sensitivity analysis of possible public and private actions in the future; performed with the I-O table. Time period t is a nominal index for the year forecasts are desired. For example, if forecasts are desired for 10 years from 1980, then t is 1990. V can be calculated as the sum of profits, payments to governments, and payments to households divided by total output for each sector. As discussed above, these represent social preference weightings. Therefore, they may be altered from the raw data to favour or disfavour certain industries. X is total output at time t. l is the land input coefficients at time t; measure in hectare-square metres. I-A is the Leontief matrix representing an industry by industry technological matrix at time t. L is the total amount of land required at time t as a function of X_t and l_t. F is the final demand at time t.

Second, capital and labour supply growth potentials would be determined. F would be adjusted to reflect any capacity constraints on labour and capital. Initially land constraints, L, would not be adjusted accordingly; adjusted by the output results from final demand constraints reflecting capital and labour shortage. Using the first approach above, the planner can determine which industries would be constrained by capital and labour supplies and, potentially, by land supplies. The result would indicate which inputs (capital, labour, land) would constrain output and their value to output of a region. This may provide useful information for purposes other than the primary purpose of land use allocation. Then output would be adjusted to reflect capital and labour shortages as calculated in final demand.

Third, the second approach would be used. Note, the final demand constraints could be dropped because they are already included in the land constraints. Thus, the total land, Lo, that would just constrain output would be determined. Land amounts are then transformed into two dimensional figures; that is, hectares. This is done with density assumptions to ensure demand (Lo) equals total available "productive" supply. "Non-productive" uses could include, for example, nature conversion, open space, recreation land, and special control areas; but would not include farmland. Each sector's use could be adjusted proportionately to Lo. At this point, the planner has an index for the opportunity cost of "non-productive" land uses. The index is the shadow price for Lo.

Finally, the third approach could be used. The land constraints determined in the second approach would be used as the L constraints.

Also, the final demand constraints would not be included since labour and capital constraints are already included in land constraints. The land amounts would then have to be adjusted by present stock to indicate amount of development or redevelopment, that is, growth will take place. The third approach gives in some sense the most "efficient" allocation of land among competing uses. It essentially gives the planner a tool to answer their "type" and "how much" questions. More importantly, the tool does so by applying the economic efficiency criteria. Therefore, that allocation is optimum from an economic point of view. This is the primary function, as discussed above, of the land use plan design.

To some extent the "type" question is predetermined by the land use categories the analyst chooses to use as constraints. For example, they may include, as in the Regional Plan; general urban, urban reserve, general industrial, industrial reserve, agricultural, and country residential. The model developed here, however, is more fruitful. Given the optimum outputs, X, and land use output coefficients, one can determine the amount of land required for each industry. As an extension, industries with the same design standard requirements could be aggregated into groups. These groups would represent land use "types". The planner would have, thus, a comprehensive and detailed indication of the relative and absolute demand of land uses. As a spin-off, this could serve as a basis for utility service, and municipal and provincial taxation projections.

To summarize, this chapter has explored a number of input-output and linear programming approaches to regional land use planning. Some of the work, especially the third approach, is quite original. It represents the

theoretical contribution of this thesis. Potential application procedures were also discussed. The analysis of land use models and macroeconomic models along with the potential application procedures are the practical contributions of this thesis.

Footnotes

[1]Roland Artle, *The Structure of the Stockholm Economy: Toward a Framework for Projecting Community Development,* (New York: Cornell University Press, 1965).

[2]The actual methodology Artle used is unclear; see Ibid., pp. 59, 91, 99. The method reported above is an interpretation. It is a theoretically valid method of developing such a table.

[3]Ibid., p. 16.

[4]W.Z. Hirsch, "Application of Input-Output Techniques to Urban Areas" in T. Barna, ed., *Structural Interdependence and Economic Development,* (London: MacMillan & Co. Ltd., 1963).

[5]For a comprehensive overview of linear programming applications to plan design see C.D. Laidlaw, *Linear Programming For Urban Development Plan Evaluation,* (New York: Praeger, 1972).

[6]In England, current problems with objectives and constraints in structure plans include: too high level of abstraction; not playing a very significant part in the subsequent plan-making process; priorities not defined explicitly; and little quantified performance criteria, that is, measuring the extent to which particular proposals meet stated plan objectives. See, R. Barras and T.A. Broadbent, "The Analysis in English Structure Plans," *Urban Studies* 16 (February 1979), pp. 1-18.

[7]Kenneth J. Schlager, "A Land Use Plan Design Model," *Journal of American Institute of Planners,* 31 (May 1965), pp. 103-11.

[8]Bruce G. Boaden, "Choosing the Optimal Land Use Mix: A LP/DCF Model," *Urban Studies* 14 (June 1977), pp. 207-210.

[9]This can be argued for any policy evaluation, however, with specific application to land use, see W.I. Morrison, "Input-Output Analysis and Urban Development Planning: Some Applications of the Peterborough Model," in W.I. Grossling, ed., *Input-Output and Throughout,* (London: Input-Output Publishing Co., 1971).

[10]For an argument that this is the planner's objective, see A.W. Evans, "Two Economic Rules for Town Planning: A Critical Note," *Urban Studies* 6 (June 1969), pp. 227-234.

[11]Land input coefficients for the same industry are expected to be different for different land uses. First, land, as the negative rent gradient indicates, is not homogeneously priced. Thus, the output per hectare or output per square meter (assuming a capital-land elasticity of less than unity) will have to be higher; for example, in the center of the city then in the suburbs. Second, requirements for buffers, parking, etc. given different amounts of land different efficiencies with regard to their building area ratios. Third, from the demand side, the volume of business is different in different locations.

[12]Forcing the model to have equality constraints for land uses.

[13]The amount of each land use is not fixed in the technical sense. At this point, the planner, exante, is free to arbitrarily allocate different amounts of land to different uses. However, given assumptions about densities, there is a limit to the total amount of land available to be allocated.

[14]The idea for this constraint formulation was taken from E.M. Lofting and P.H. McGauhy, *Economic Evaluation of Water, Part 10: An Input-Output and Linear Programming Analysis of Californian Water Requirements,* No. 116, (Berkeley: UCLA Water Resources Centre, 1968), Chap. VI.

[15]An inequality sign ensures positive shadow prices. The shadow prices are important for the planner's consideration, therefore, the inequality sign is preferred to the equality sign.

[16]For an elaboration of the argument that follows, see Melville McMillan, "Economic Rules for Planners: A Reconsideration," *Urban Studies* 12 (1975), pp. 329-333.

[17]This proposition was presented by W. Lean and B. Goodall, *Aspects of Land Economics* (London: The Estates Gazette 1966) as reported in McMillan, "Economic Rules."

[18]Albeit still compatible with the above rules, see McMillan, "Economic Rules."

[19]Ibid.

[20]J.M. Henderson and R.E. Quandt, *Microeconomic Theory* (New York: McGraw-Hill, 1938), pp. 12-16.

[21]Robert Dorfman, Paul A. Samuelson and Robert M. Solow, *Linear Programming and Economic Analysis* (New York: McGraw-Hill, 1958), p. 166.

[22]The following, I believe, is the first exposition of the solution to the allocation problem in this format.

[23]I am deeply indebted to Professor B. von Hohenbalken of the University of Alberta for the mathematical derivation of this constraint procedure.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

As a result of the analysis above the following conclusions are made:

a) The present land use forecasting practices in the Edmonton region are inadequate. The inadequacies are in terms of forecast accuracy and the ability to determine the optimal or, that is, efficient allocation of land.

b) Land use models which are designed to allocate the forecasted land demands to a large number of small zones within a region are unsuitable. The major problem is the inability to accurately forecast all land uses in a large number of small zones in the long term.

c) Of the macroeconomic approaches, input-output is the most accurate and has the most uses.

d) A land use model which can forecast all land uses in the region and determine the efficient allocation of land to these uses is theoretically feasible.

The recommendation of this thesis is that the above land use planning model should be operationalized in the Calgary region, the Edmonton region or both.

The benefits of this approach, it was argued, are in terms of the increased accuracy and the number of uses. The increased accuracy is, if nothing else, a natural result of the extensive gathering and analyzing of

[illegible]

[illegible]

[illegible]

information required to build the model. All the social-economic benefits from more accurate forecasts are difficult to measure precisely. A case study in North Dakota, however, found that a 10 per cent increase in accuracy would produce social-economic benefits of .31 to 3.6 million dollars.[1] These estimates were based on a population change of only 8,000 people. Also, they did not consider all possible social benefits. These figures, therefore, are quite conservative relative to the potential benefits to the Edmonton region. Besides forecasting future growth, the input-output framework has many policy and impact applications for a regional or general plan. The "planning" benefits from these uses is not limited to a regional or general plan.

The more day to day decisions of the planning process can also benefit from the numerous applications of the model. One area of usage is the planning for future transportation, utilities, telephones, and other infrastructure. With this type of a model at their disposal, municipal authorities could analyze the impacts on land use, taxes, and utility service requirements from: (1) higher level government policies such as the National Energy Program; (2) private sector developments such as Alsands; or (3) lower level government policies such as land banking. This approach, it is argued, would result in benefits not only from increased accuracy for individual civic department planning but also consistency in planning among departments. For example, the building of roads and the servicing of lots are often built far in advance of actual demands. This results in a large waste of money in the form of unused capital sitting in the ground. On the other hand, infrastructure which lags demand results in inflated prices for land and congestion costs. More accurate forecasts of future demand for infrastructure would reduce these costs.

A second area where an input-output table can be used on an on-going basis is in the area of economic development. The types of analysis that can be carried out within this framework include: self-sufficiency analysis, income and employment impacts, stability analysis, import substitution, bottleneck impacts, factor input shortages, and economic interdependence among regions. A third area is the consideration of any ecological or social aspect of the economy in terms of impacts or descriptive interrelationships. Finally, input-output is without competition as a descriptive tool for the economic interrelations among decision units in an economy. This is important to policy-makers, planners, educators, and students in increasing their understanding of the urban economy. Policy-makers and planners need an understanding of how the economy works to make appropriate policy decisions on a day-to-day basis. Educators and students of economics, urban geography, and planning could benefit from this research and educational tool.

The contributions of this thesis have been both practical and theoretical. Considering its broad scope one can identify one major limitation. The limitation is found in the costs involved in constructing an operational model. The costs are extensive, given, as argued above, that a survey approach is required. From one perspective, one must consider the cost net of funds allocated to all other research that would be covered by the model. Many, if not most, civic departments and the Edmonton Regional Planning Commission perform separate forecasts of economic, social, and demographic activity within the region. This multiplicity of predictions is not only costly because of the duplication but costly because of the lack of coordination and consistency in the methodology employed in preparing such forecasts. In short, it would be

highly beneficial to utilize a general model which had a well-defined methodology and, at the same time, satisfied all of the objectives of various concerned parties.

From another perspective, as discussed above, one must consider all the social-economic benefits from better forecasts. Based on the North Dakota figures, one could argue, albeit crudely, that the social-economic benefits will certainly outweigh the costs of building the model.

Also, the costs and time required to build the model could be reduced substantially if a "non-survey" approach was used. The argument for a complete "survey" approach was based primarily on the forecasting accuracy for a regional plan. If less than survey built accuracy (especially for day-to-day planning purposes) is sufficient then a non-survey built table could be developed at a significantly reduced cost. Input-output tables presently exist for the Canadian economy and for the Alberta economy. A non-survey approach would utilize much of the information that already exists, that is, the Alberta input-output table, to develop a regional input-output table for the Edmonton region or the Calgary region. A "balanced" approach could be used where national and provincial impacts on the region could be analyzed. The suitability of the non-survey approach depends on the additional applications of the users and their acceptable degree of forecasting error.

Another consideration is the apparent lack of dynamic and spatial analysis. One dynamic approach would be to determine shadow prices in each time period and optimize them over the life of the plan. The result would be an optimal staging of growth. The model developed in this thesis actually does have a dynamic element in it; albeit a different one. In long run forecasts, the I-O table is made dynamic by adjusting the capital

formation coefficients for capacity constraints. Also, the model can be applied for any time period. Thus, while it is not an "optimal-dynamic" approach, it can be considered a dynamic one. In terms of spatial analysis, it was argued above that intra-regional analysis (allocation of activities to specific zones within the region) should not be developed. Intra-regional analysis is possible with the I-O tables. An intra-regional table covering the province would be useful. Each sub-region section of the table could be associated with each region in the province. The dynamic and intra-regional issues are matters warranting future research.

This paper has made a number of contributions. Contributions have been made to regional planning; in the Edmonton region, Alberta, and planning general. For the Edmonton Region and Alberta, it introduced an applied technique to link economic planning and land use planning. The link is achieved by using the I-O table for economic planning and the I-O linear programming model for land use planning. This is important because economic allocation determines land use allocation. For planning in general, the contribution has also been in linking economic and land use planning. This contribution was the applied technique for allocating land uses based on economic efficiency. In sum, a feasible and useful plan design tool has been developed.

Another contribution has been made to the field of economics. This paper has introduced a practical technique to determine the efficient allocation of inputs when the amount of available inputs are not specified and the market has not determined their prices.[2] That is, inputs are not scarce in a technical sense, but scarce when regulations limit their use. In this sense, the allocation mechanism is not the market but the regulatory agency. When the inputs, as such, have not been given a price

by the market, the agency, therefore, can not recommend an economically efficient allocation. The technique developed in this thesis is capable of dealing with this problem.

The recommendation of this study is for the Province of Alberta to establish a program to operationalize the model developed here in general form. Ideally, as with the Vancouver experience, the program would be funded and administered jointly by the University of Alberta, Province of Alberta, Government of Canada, Edmonton Regional Planning Commission, and the Cities of Edmonton, Calgary or both. As a first step, the program would determine the potential users, types of uses, model structure, and cost.

Footnotes

[1]Mark S. Henry, "On the Value of Economic-Demographic Forecasts to Local Governments," *The Annals of Regional Science*, 14 (March 1980), pp. 12-20.

[2]To my knowledge, this technique has not been introduced before.

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APPENDIX A

FACTORS USED IN FORMULATION OF INDIVIDUAL LAND SUITABILITY MAPS

1. General Urban and Urban Reserve Land Classes

    a) Groundwater recharge map (on file)
    b) Generalized topography map (Vol. 1)
    c) Soils map (Vol. 1)
    d) Surficial deposits map (Vol. 1)
    e) Groundwater yield map (Vol. 1)
    f) Urban Land Use policies
    g) Existing urban areas and infrastructures
    h) Areas committed to urban in PRP (Metropolitan Part), statutory plans and by-laws
    i) Land Use compatibility
    j) Financial ability of municipality to provide support services
    k) Amount of vacant urban land
    l) Population projection to 1986
    m) Land ownership characteristics
    n) Areas committed to Urban Reserve/Residential Reserve in PRP (Metropolitan Part), statutory plans and by-laws
    o) Population projections to year 2001

2. General Industrial and Industrial Reserve Land Classes

    a) Groundwater recharge map (on file)
    b) Generalized topography map (Vol. 1)
    c) Soils map (Vol. 1)
    d) Surficial deposits map (Vol. 1)
    e) Groundwater yield map (Vol. 1)
    f) Economic and Industrial Land Use policies
    g) Existing industrial areas and urban infrastructure
    h) Areas committed to Industrial in PRP (Metropolitan Part), statutory plans and by-laws
    i) Land use compatibility
    j) Availability of labour pool
    k) Financial ability of municipality to provide support services
    l) Amount of vacant industrial land
    m) Recent economic and industrial land development trends/prospects
    n) Areas committed to Industrial Reserve in PRP (Metropolitan Part), statutory plans and by-laws
    o) Long-term (20-25 years) economic/industrial land development prospects

3. Agricultural: Farmland Conservation Land Class

    a) Prime agricultural lands map (Vol. 1)
    b) Agricultural Land Use policies
    c) Areas committed to Agriculture in PRP (Metropolitan Part)
    d) Areas committed to Agriculture in statutory plans and by-laws

4. Agricultural: Country Residence Land Class

a) Soils
b) Groundwater yield map (Vol. 1)
c) Surficial deposits map (Vol. 1)
d) Generalized topography map (Vol. 1)
e) Floodplain areas map (on file)
f) Groundwater recharge map (on file)
g) Country Residential Land Use policies
h) Existing multi-parcel concentrations of CR development
i) Areas committed to CR use in PRP (Metropolitan Part)
j) Areas committed to CR use in statutory plans and by-laws
k) Amount of vacant CR land
l) Population projections
m) Land use compatibility
n) Detailed CR study by Commission Staff in selected portions of the Region

5. Resort Land Class

a) Soils map (Vol. 1)
b) Groundwater yield map (Vol. 1)
c) Surficial deposits map (Vol. 1)
d) Generalized topography map (Vol. 1)
e) Floodplain areas map (on file)
f) Groundwater recharge map (on file)
g) Lake Shoreland Use policies
h) Stream Shoreland Use policies
i) Existing Summer Village and resort areas

6. Nature Conservation, Open Space and Recreation Land Class

a) C.L.I. Recreational capability map (Vol. 2)
b) Critical Wildlife areas map (Vol. 1)
c) Surficial deposits map (Vol. 1)
d) Generalized topography map (Vol. 1)
e) Groundwater recharge map (on file)
f) Floodplain areas map (on file)
g) Primary and Secondary Wildlife Protection Areas Map (Vol. 2)
h) Existing Provincial and Municipal parks
i) Areas reserved or acquired for public parks
j) Areas committed to Recreation/Open Space in PRP (Metropolitan Part)
k) Areas committed to Recreation/Open Space in statutory plans and by-laws
l) Open Space and Outdoor Recreation Land Use policies
m) Stream Shoreland Use policies
n) Lake Shoreland Use policies
o) Fish and Wildlife Habitat Use policies

7. Special Control Area Land Class

a) Boundaries of Regulated Lake Shorelands
b) Boundaries of Priority Lake Shorelands (established by Commission staff)
c) 35 N.E.F. (Noise Exposure Forecast) contours of airports
d) Restricted Development Areas (RDA's)
e) Cooking Lake Moraine Study boundary
f) Forest Protection Area (Green Zone) Boundary
g) Valuable sand, gravel and coal deposits map (Vol. 2)

SOURCE: Edmonton Regional Planning Commission, *Edmonton Regional Plan: Draft,* 2 Vols., Vol. 2, Appendix B-3.0

APPENDIX B

PURPOSE OF MODELS

Models can be classified according to three basic purposes. First, *descriptive* models categorize and relate much about the inner workings of the urban environment that affect its structure. For these models it is sufficient to know that the endogeneous and exogeneous variables are related. The statistics, thus, are non-parametric. Second, *forecasting* or *projection* models involve parametric relationships between the endogeneous and exogeneous variables. Included in this category are *estimation, prediction* and *impact*. Estimation involves determining future values for the exogeneous variables, and through the model, relating these values to determine estimates of endogeneous variables. Prediction is synonomous with conditional estimates or policy analysis. The idea is to preset values on parameters in the model to observe the impact on the endogeneous variables. Impact is closely related to the latter, but more concerned with market than policy impacts. For example, the impact of a new industry locating in the urban area as opposed to a policy impact of increasing transportation prices. The above two categories, descriptive and forecasting, are considered to be *positive* models because they model what is or what will be. Also, in general terms, they are referred to as *market analysis* tools.

Third, a model can be used for *planning*. They are *normative* models. The planner sets up a set of goals and from these (measurable) objectives. These are value laden assumptions of what would be "good" for society or what it should strive for. Alternate means to achieving the objectives are determined and evaluated. The most "suitable" means are chosen.

APPENDIX C

GROWTH AND CHANGE

GOAL 1: A strategy for the accommodation of growth which reflects the principles of conservation of natural resources and the efficient use of land in the Region.

GOAL 2: Population distribution in a manner which maximizes accessibility to and efficient use of transportation, education, recreation, health care and social facilities, and services.

GOAL 3: A Regional urban structure which provides the opportunity for all people of the Region to obtain adequate housing in locations convenient to facilities and in well planned communities.

GOAL 4: Management of urban growth in a manner responsive to local desires, historical factors and social, cultural and environmental values.

GOAL 5: Creation or re-inforcement of a sense of Regional and community identity in all parts of the Region.

GOAL 6: A prosperous and stable economy containing a variety of employment opportunities in proximity to places of residence.

GOAL 7: Opportunity for citizens and communities to share in the economic growth of the Region.

TRANSPORTATION AND UTILITIES

GOAL 8: A safe, efficient and convenient multiple-mode transportation system that is integrated with land use and is consistent with the city-centred region concept of the Plan.

GOAL 9: Efficient and adequate water, sewer and solid waste disposal services for all of the Region's residents.

PHYSICAL ENVIRONMENT

GOAL 10: Protection of extensive open space and sensitive or unique areas.

GOAL 11: Wise and efficient use of land and other resources of economic importance to man.

GOAL 12: Conservation of valuable non-renewable resources for future use and benefit of the Region.

GOAL 13: Compatibility and harmony between the natural environment and human development.

GOVERNMENT AND CITIZEN CO-OPERATION

GOAL 14: An effective Regional Planning Commission.

GOAL 15: Improved inter-municipal and inter-governmental co-operation.

GOAL 16: Opportunities for citizen participation in the decisions that shape the Region.

SOURCE: Edmonton Regional Planning Commission, *Edmonton Regional Plan: Draft*, 2 Vols., Vol. 2, pp. 2-8, 2-9.